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MORPHOPHYSIOLOGICAL ANALYSIS OF ORGANOGENESIS OF SOME VARIETIES OF THE GENUS CYMBIDIUM UNDER CLOSED CONDITIONS

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Abstract.

The article presents the results obtained under indoor conditions in the study of biomorphological and morphophysiological features of some varieties of the genus Cymbidium, the change of age periods in ontogenesis, especially the development cycle of vegetative and generative shoots. Morphophysiological studies have shown that in stage I of organogenesis, regardless of type, new shoots of Cymbidium are formed from the previous vegetative shoot in the form of an axillary meristem, while it is still in the phase of internal bud development. At stage II of organogenesis, a year after the beginning of shoot growth, 8-11(12) primordium leafy shoots surrounding the growth cone are formed from its axillary meristem. In August-October, the growth cone of the generative shoot differentiates, i.e. the generative shoot enters stage III of organogenesis. During this period, the generative shoot begins to grow intensively and enters stage IV of organogenesis. At this time, the axis of the inflorescence is formed, the basis for flower formation is laid, then the flower base, pistil and stamen are formed. At the V stage of organogenesis, in the second decade of July, mass formation of generative shoots is observed. Formation and development of flowers in the inflorescence occurs acropetally. At this time, all flower organs grow very slowly, and only shortly before flowering the plant enters the VI-VIII stage of organogenesis. Depending on the variety, stage IX of organogenesis occurs in December-February and lasts until May. Fetal formation, growth and development (X-XII stages of organogenesis) takes 10-12 months. As the fruits mature, the generative shoot withers, which means the completion of its development cycle. Thus, the studies have shown that the process of organ formation in orchid shoots is subject to general biological regularity and combines features characteristic of certain species and varieties.

Keywords: tropical orchids, biomorphology, morphophysiology, ontogenesis, morphogenesis, vegetative and generatives shoots

Introduction

The study and cultivation of ontogenesis, especially the cycle of development of various organs, of tropical and subtropical plants under closed conditions conditions has shown

that the development of rational technology for breeding new species in industrial floriculture is impossible without studying their biomorphological and morphophysiological features, especially the morphological structure

of individual shoots and age-related changes in ontogenesis. To determine the regularities of formation of individual organs and the plant as a whole, it is necessary to know the biology of the development of juvenile plants of some orchid species (Gasimov Sh.N., 2020; 2025; Rao A., 2018; Besedina, 2018; Buyun L.I., 2018; G.L., Cherevchenko, 2016; Nongdam P., Chongtham N., 2012).

During the research period, a comprehensive agrotechnical study of the cultivation of the tropical genus *Cymbidium* of the *Orchidaceae* family under closed conditions was carried out, its biomorphological and morphophysiological characteristics, age changes in ontogenesis, and especially the development cycle of individual shoots were studied. The study of the complete development cycle of *Cymbidium* is of scientific and practical importance in terms of the study of orchids. At this time, the boundary between the vegetative and generative periods and its transition to the senile period is determined. In this regard, the duration of flowering, age periods and development patterns of individual *Cymbidium* plants of 9 varieties of the genus under indoor conditions were studied.

The study of the development of juvenile plants of cymbidium at the initial stage is of great theoretical and practical importance. The mastery of the biotechnology of this promising plant, which is used to enrich the assortment of plants of the cultivated flora cultivated under indoor conditions, is extremely important.

The object and methodology of the research

The research was conducted under closed conditions in the dry subtropical region of Azerbaijan. The genus *Cymbidium* which is the subject of the study, is represented in the collection by 9 hybrid varieties cultivated under closed conditions: *C. Oriental Legend Cinnamon*, *C. Clarisse* car. "Majestic", *C. Kinglet "Emerald"*, *C. Cooksbridge "Pinkie"*, *C. Ruspex Fawn.*, *Cassandra*, *Genifer*, *Baliks*, *Durhan Castle Irene*. The

results obtained in the study of these varieties are summarized on the example of *Cymbidium hybridum*.

The graphic description of the morphogenesis and seasonal development rhythm of plants was carried out according to the methodology developed by V.V. Skripchinsky, Y.A. Dudar and G.T. Shevchenko (Skripchinsky et al., 1970).

During the study period, biometric measurements of the tuberidium, leaf and root of a model plant isolated from a clone of *Cymbidium hybridum* were taken twice a month, from August to October. The structure of all shoots and the state of the apical meristem of tuberidium were studied using a binocular microscope (MBS-9). The morphophysiological analysis of the stages of organogenesis was studied using the methodology of F.M. Kuperman (Kuperman, 1968).

Cymbidium hybridum has two types of shoots, vegetative and generative, which have similar structures during internal bud development and sometimes consist of 10-14 embryonic leaves. The difference between them is that during the period of intensive growth, the vegetative shoots form leaves and thicken their spines, i.e., the formation of tuberidium, and the apical meristem is clearly in a vegetative state. Bracts are formed in the generative shoot.

Results and Discussion

The growing rows of orthotropic shoots of old *Cymbidium* plants form a complex basisypodial system. This small developmental cycle is understood as the complete developmental cycle of individual shoots that are part of a larger developmental cycle, i.e. the entire system of shoots of a clone. The layout and structure of vegetative and generative buds in the tuberidium of the *Cymbidium hybridum* was studied (Figure 1).

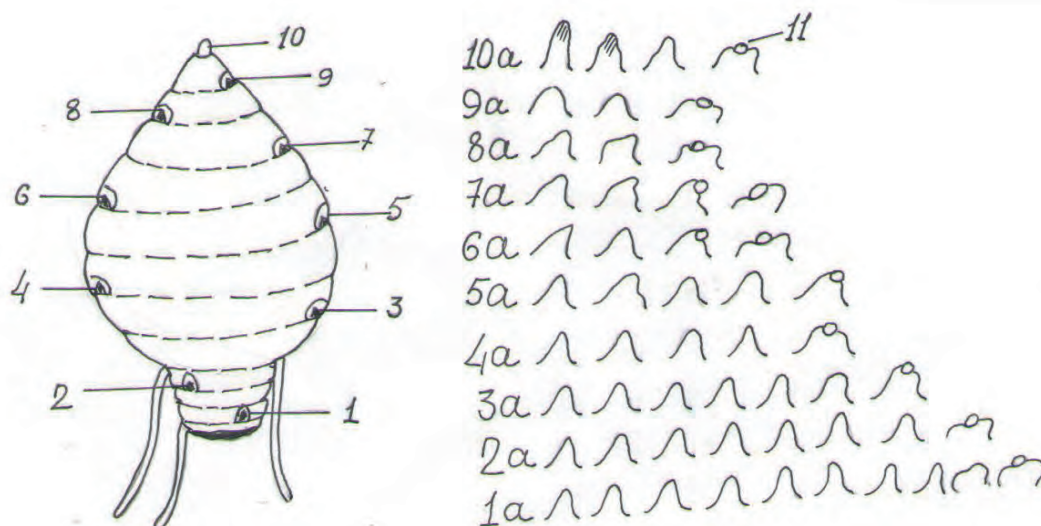


Figure 1. Schematic of the layout and structure of buds on the tuberidium of *Cymbidium hybridum* 1-9 – buds located in the axils of the leaves; 10 – terminal bud; 1a – 10a – elements forming the buds on the tuberidium: the number of embryonic leaves; 11 – growth points

Studies have shown that at stage I of organogenesis, regardless of type, new shoots of *Cymbidium* are formed from the previous vegetative shoot in the form of an axillary meristem, while the shoot is still in the internal development phase. At stage II of organogenesis, one year after the shoot starts growing, 8-11(12) primordium leafy shoots surrounding the growth cone are formed from its axillary meristem. Usually, the first and second leaf axils of the embryo (primordium) have areas of unformed meristem swellings. They are usually absent in the axils of other leaves. In the second year, shoots undergo the internal bud phase.

In the third year, young vegetative shoots with tuberidium and leaves develop from the formed bud. At the same time, when suitable conditions occur, generative shoots develop at the second stage of organogenesis (Figure 1). In the latter case, the growth of bud occurs later, in late June - early July. In the fourth year, the more developed buds of the lower vegetative shoots of tuberidium continue to vegetate and sometimes the numbers of leaves increase, young vegetative and generative shoots of the next row develop. It should be noted that at the initial stage of development, vegetative and reproductive shoots are difficult to distinguish in the bud phase. Because the shape and

size of the shoots (9-11 embryonic leaves) are the same. It has been established that vegetative shoots develop the following year from the lower shoots of tuberidium, from the axils of the embryonic leaves, which are meristem swelling. Generative shoots usually develop from the third - fifth buds, or sometimes from shoots above but lacking a meristem center, and the scale-like leaves - the bract are formed from the embryonic leaves on the floral axis. In August-October, differentiation of the growth cone of the generative bud occurs, i.e. the generative shoot enters stage III of organogenesis. During this period, the generative shoot begins to grow intensively. It emerges from the axil peduncle, pistil and stamens are formed. of the covering leaf within a short time (2-3 weeks) and enters stage IV of organogenesis. At this time, the inflorescence axis is formed, the basis for flower formation is laid, then the of the covering leaf within a short time (2-3 weeks) and enters stage IV of organogenesis. At this time, the inflorescence axis is formed, the basis for flower formation is laid, then the peduncle, pistil and stamens are formed.



Figure 2. Development of the flower stalk in a hybrid cymbidium

It should be noted that the initial period of formation of the reproductive organ of *Cymbidium* is very short, and the conditions necessary for the beginning of the development of its generative organ are very specific. This period is called the critical period or natural flowering goal. In order for plants cultivated under closed conditions to successfully pass this stage and form many generative stems, it is necessary to know their morphophysiological state and the complex of physical factors. This is necessary for the formation of axis and flowers.

During the period of early development it is not difficult to determine the beginning of generative bud formation. At the beginning of development, when buds 1-2 cm high began to grow, no changes in growth were detected. However, during this period, differentiation of the growth cone of generative buds occurs and the bud moves to the next stage of organogenesis. Since the transition of the growth cone to the prefloreal state in *Cymbidium* occurs rapidly, within a few days, it is not detected even with frequent inspection of the plants. Individual generative shoots appear on the surface of the substrate at the end of June, and en masse in July. This can be visually detected when the shoots reach a height of 3-4 cm. Generative shoots are more dense, have the shape of a truncated cone, the tip is not sharp. These shoots grow very intensively in August-September.

Usually at stage V of organogenesis, in the second decade of July, mass formation of generative shoots: inflorescence, pistils, stamens is observed. Formation and development of flowers in the inflorescence occurs in acropetal order.

The apical meristem of a flowering shoot remains active for a long time, forming new flowers. At this time, all the organs of the lower flower are already largely formed. Some flowers at the top of the inflorescence do not reach normal development. The upper flowers lag behind the lower flowers in development and usually dry up at stage V. According to observations, they account for 30-35%. Thus, of the 18-19 floral primordium formed by juvenile cymbidium plants, only 13-14 develop normally. Immature flowers are either in the flower swelling stage or at the beginning of organ differentiation. During this period, the length of five or six flowers at the top of the flower cluster does not exceed 10-12 mm. By the degree of inflorescence growth, when its height reaches 9-11 cm, sporogenic tissues are formed in the anther. In the inflorescence, the duration of the period of flower initiation and differentiation (stage V) is characterized by two features: the formation and formation of flower organs is very slow, and a new flower bud is formed in the apical meristem of the inflorescence over a very long period of time.

It can be assumed that at the beginning of stage V, by changing the day length and temperature regime, it is possible to equalize the level of flower development along the inflorescence length. Thus, by synchronizing the development of all flowers in the inflorescence, the yield of the cymbidium plant can be significantly increased. This method of synchronization probably comes from the search for optimal conditions for the passage of stage V. Stage V of organogenesis lasts for a long time and lasts from August to February.

It is necessary to dwell on stage V in detail, as it is one of the longest stages requiring a special approach in the development of cymbidium cultivation technology. According to our observations, in conditions of dry subtropics it begins in early June. During this period inflorescence height reaches 0.6-1.8 cm and in rare cases - 5-8 cm. Already at the beginning of stage V, the generative shoot can be visually distinguished from the vegetative shoot because the bract closing the flower axis are inclined, while in this phase two of the three bract tightly attached to the flower axis are reduced and close the flower axis, forming a truncated cone. Depending on the cultivar, the period of meiotic archesporium cell formation in the pollen of the mother cell lasts until October-November. Thus, in the variety *C. Ruspex* Fawn meiosis in the mother cell was recorded at the end of November, and in the variety *C. Cooksbridge* "Pinkie" - in the middle of December. Flowering (stage IX) begins in December-February, depending on the cultivar, and lasts until May. Flower unfolding occurs in an acropetal sequence with an average interval of two to four days. Sometimes this sequence is broken, and flowers located higher up (2-3 buds) rather than the next flower bloom. This is probably due to mechanical damage to the peduncle, part of the flower axis or physiological abnormalities.

It takes two to three weeks from the first flower at the bottom of the inflorescence to the last one, depending on their number. At the stage when the inflorescence begins to develop, from the moment it emerges from the bract that covers it until it blooms, it takes 1.5-2 months. Depending on the variety, the blooming of a flower lasts 15-30 days, regardless of its position in the inflorescence.

Observations have shown that the physiologically active period of the pistil stigma begins five to seven days after flowering and lasts 10-15 days. During this period, pollinated flowers produce a maximum of seeds. Flowers can be pollinated after 15 days of flowering, but during this time, seed yield and seed quality will decrease significantly. In this case, the fruits often turn yellow and the informal seeds spill out four to five months after pollination. This phenomenon

is observed in a inflorescence when five to seven flowers are not pollinated. Symbidium, often consisting of four to five stems, ensures normal development of one to two fruits. The rest of the fruits fall at any stage of development.

Fruit formation, growth and development (stages X-XII) takes 10-12 months. Simultaneously with fruit ripening, the generative shoot withers, i.e. its development cycle is completed.

The development cycle of a generative shoot ends in the fourth year, when its base is laid. The vegetative shoot that gave rise to the generative shoot continues its development in the fifth year, but the number of leaves, as a rule, does not increase, and the activity of the apical meristem weakens. In rare cases, another flowering shoot develops from this shoot. The vegetative shoot in the sixth year still has succulent tubers and green leaves, but no new growth is observed, the apical meristem completely ceases its activity and its cells become parenchymatous. In the seventh year, the leaves gradually begin to shrivel up, and in the eighth to ninth year, only axillary buds remain on the tuberidium, densely covered with dry leaf sheaths, which perform a reserve function. They can develop when the tuberidium is destroyed or damaged. In this case, the leaves in the basal part of the tuberidium gradually dry out. At the same time, the root of the shoot dries up, the life process of the leafless tuberidium continues at the expense of the rhizome connecting it to another shoot of the plant, as well as at the expense of its own reserves accumulated during the period of intensive vegetation.

Thus, the vegetative shoots of the cymbidium plant have a sympodial branching system. Each shoot has an independent root system, a small rhizome with 10-15 axillary shoots connecting it to the previous shoot. In the first year of vegetation, leaves are actively formed from the apical meristems of vegetative shoots.

The studies have shown that the number of years during which a leafless tuberidium can exist in case of gradual drying of leaves from the basal part to the apical part until the next reserve shoot and root dry up depends on how many reserve shoots it has. Thus, the development cycle of a vegetative shoot ends 10-15

years after its formation.

The most developed shoots are located in the zone of rhizome-tuberidium transition. They reproduce the next row of shoots capable of entering the generative phase. During the inner bud phase and the first year of vegetation, the apical meristem of the vegetative shoot actively forms leaves. Sometimes a few leaves are formed in the second year, in the third or fourth year of development the meristem activity weakens, and in the fifth year it completely ceases its activity.

When the shoot reaches a height of 12-15 cm, its root system begins to develop. The root system consists of numerous roots, sometimes reaching a length of 40 cm, branched to the third order. A rhizome with a diameter of 2-3.5 cm unites all shoots during its full development. Almost every year the roots are completely renewed (April-May). The viability of the shoot root system is observed for six to seven years, and its destruction occurs simultaneously with the drying of leaves.

Eight - ten years old shoots, which are deprived of leaves and roots and which are connected to other shoots by means of rhizome, form tuberidium. Tuberidium lives off its own reserves, and at the same time our studies have shown that it has some phytohormonal connection with the young shoots of the plant through the rhizome. Every year in March-April, when the young shoots of the clone begin to grow, the shoots of the lower tier begin to swell. If they do not swell, the middle or upper shoots swell. When the height of the growing young shoots reaches 5-8 cm, the swollen shoots of the old tuberidium gradually die off.

Therefore, the life expectancy of an individual vegetative shoot of cymbidium, as the basic structural unit of perennial plants, is 10-13 years. The internal phase of bud development

is equal to two years, and the intensive vegetation period is four years. Then, during three to four years (sometimes more) there is a process of weakening and drying of shoots. Usually vegetative shoots form generative shoots in the second or third year of vegetation. Their number depends on the number of buds developed in the lower tier.

The generative function is performed by specialized shoots, whose life span is much shorter than vegetative shoots - about four years. In these shoots, the intraspecific phase of the shoot is equal to about two years, as in vegetative shoots. Flowering and fruit ripening also take two or three years, after which the generative shoot withers.

The length of the shoot development cycle depends on the growing conditions and human intervention in cloning. Human intervention consists of systematic separation of old shoots from young shoots.

Thus, the studies conducted have shown that the process of organ formation in orchid buds obeys general biological regularity and has characteristics specific to a particular species. Knowledge of the stages of organogenesis of hybrid cymbidium is important for the development of its biotechnology, since the course of a particular stage depends entirely on cultivation conditions. A special role here belongs to the temperature regime, since differentiation of generative shoots occurs at low (10-13°C) temperature. The necessary conditions for successful flowering of cymbidium are considered to be thermoinduction.

Biomorphological and morphophysiological knowledge about the stages of formation of individual organs of cymbidium, especially generative organs, allows targeting the growth and development of plants.

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ENTOMOPHILOUS FLORA AND INSECT DYNAMICS IN THE ARID ECOSYSTEM OF MIANWALI

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Abstract. *A study was conducted to examine plant diversity and insect relationships between plant species in the arid zone of District Mianwali in Punjab. This area provides suitable conditions for plant-insect research due to its dry sandy loamy soil characteristics. Researchers compiled a complete list of 79 entomological floral species, including culinary herbs, medicinal plants, and crops, while documenting ecological preferences, life forms, flowering times, and conservation status. The study evaluated entomological processes by tracking pollinators and herbivorous insects in the environment. The research demonstrates that arid ecosystems contain numerous entomophilous plants that play essential roles in ecological stability. The study showed that pollinators and herbivores are specifically linked to diverse plant groups, creating beneficial relationships that impact plant production. The research highlights the importance of using sustainable farming methods to protect biodiversity in the arid Mianwali region.*

Keywords: *Entomology, Floral diversity, Ecology, Medicinal Plants, Insects*

1. Introduction

The arid zone within District Mianwali, Punjab inhabits the north-western section of Pakistan and encounters specific ecological and environmental struggles. The region experiences unpleasant hot summers followed by frigid winters in addition to sparse rainfalls and dry land conditions. The geologic characteristics determine which plant communities survive here by giving them the ability to conserve water and survive dry conditions (Khan et al., 2022). The region withstands two distinct seasons while hosting a mixture of plants that include both xerophytic species and agricultural

crops along with medicinal plants (Rizwan et al., 2023). These native species deliver critical services needed by ecosystems as well as human settlements.

The district of Mianwali hosts contrasting floral biodiversity that consists of numerous species which developed through adaptations to native edaphic and climatic factors. Arid ecosystem plant species demonstrate substantial differences in life form structures as well as during flowering seasons and environmental relationships (Zameer et al., 2015). As the base of local biodiversity plants act as the sustaining elements which enable different insect species

to fulfil essential ecological functions including pollination and pest regulation and nutrient recycling (Nicholls & Altieri, 2013). Researchers have conducted minimal investigations into entomological patterns connected to Mianwali plant species.

Entomological research of plant-insect relationships in arid territories is fundamental because it enables species coexistence and helps maintain ecosystem sustainability (Dofuor et al., 2024). The mutual connection between plants and pollinators has received various investigations but researchers have given minimal attention to the entomological characteristics of Punjab arid zone plant communities (Ramzan et al., 2021). The relationship between agricultural practices and local insects requires additional academic research. The interactions function as essential tools to advance ecological and productive agricultural techniques (Guerreiro-Moreno & Oliveira-Junior, 2024).

This research project aims at generating an inclusive plant species list for District Mianwali which focuses on species valuable for economic use or ecology or medical applications. Furthermore the study needed to examine plant-insect relationships by watching how the plants interact with pollinators and herbivores as well as other entomological factors in District Mianwali.

A study of Mianwali flora's ecological and entomological worth will enable better sustainability strategies for land management. This scientific study helps global understanding of the connection between arid zone plant diversity and insect communities. Due to rising climate change pressures we need to identify the interactions between plants and insects since this knowledge aids floristic biodiversity conservation through entomological approaches particularly in water-limited areas like Mianwali.

2. Materials and Methods

2.1. Study Area: District Mianwali

The research was conducted in District Mianwali, Punjab, which is located in the arid zone of Pakistan. The region experiences extreme weather patterns, with annual rainfall ranging from 300-350 mm and summer temperatures reaching 40°C, while winter temperatures drop

to 5°C (Khan & Muhammad, 2000). The study of drought in this region is advantageous due to the presence of sandy, loamy, and saline soil types, which allow for the investigation of plant adaptations to different environmental stress conditions (Niazi et al., 2023).

2.2. Field Data Sampling

2.2.1. Flora Identification

The district conducted field survey investigations between April and August 2024 to identify entomological plant species. Researchers categorized plants based on their life forms, flowering seasons, and ecological requirements. The taxonomic identification process was facilitated by standard floristic guides developed by Ali & Qaiser between 1995 and 2022. Scientific observations of insects interacting with target plant species were conducted regularly during their peak blooming period. The observation period focused on pollinators, including bees and butterflies, as well as herbivorous insects such as aphids and caterpillars. Insects were collected using hand nets and light traps, then identified through morphological analysis using entomological keys described in Bashir et al. (2024). The authenticity of entomological plant names was confirmed using World Flora Online (<https://www.worldfloraonline.org/>).

2.3. Data Analysis

Scientists evaluated flower diversity through species richness metrics but analyzed insect species distributions according to plant group associations. Observers recorded insect visitations throughout the flowering time using Farooq et al. (2022) methodology.

3. Results and Discussion

3.1 Entomological Floral Diversity

District Mianwali exhibited 79 species of entomological flora (Table 1) consisting of herbs, shrubs, and trees where herbaceous plants composed the largest group at 63% while trees made up 24% and shrubs amounted to 13% as Figure 1 demonstrates. Agricultural areas in District Mianwali hosted wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) together with the legume crop chickpea (*Cicer arietinum*).

Several medicinal and aromatic plant species (Moringa oleifera) appeared commonly in farm fields as well as in natural environments. like coriander (*Coriandrum sativum*) and basil (*Ocimum basilicum*) together with moringa

Table 1.

Entomological floral checklist of District Mianwali

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
1.	Okra	<i>Abelmoschus esculentus</i>	Malvaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Attracts bees for pollination; pollen grains small, spherical
2.	Acacia	<i>Acacia nilotica</i>	Fabaceae	Tree	Winter (December–February)	Arid regions, sandy soils	Sandy, saline	Pollinated by ants; large, sticky pollen grains
3.	Acacia	<i>Acacia tortilis</i>	Fabaceae	Tree	Spring (March–May)	Arid regions, sandy soils	Sandy, saline	Ant-pollinated; small, sticky pollen grains
4.	Onion	<i>Allium cepa</i>	Amaryllidaceae	Herb	Winter–Spring (November–March)	Agricultural fields, gardens	Loamy, fertile	Attracts bees; pollen grains are small and light
5.	Chives	<i>Allium schoenoprasum</i>	Amaryllidaceae	Herb	Spring–Summer (April–August)	Gardens, fields	Loamy, fertile	Bees and butterflies visit; small, white pollen grains
6.	Aloe Vera	<i>Aloe barbadensis</i>	Asphodelaceae	Herb	Summer (June–August)	Dry, rocky areas	Sandy, well-drained	Attracts bees; pollen grains are granular and sticky
7.	Agarwood	<i>Aquilaria spp.</i>	Thymelaeaceae	Tree	Spring (March–June)	Tropical forests	Sandy, well-drained	Pollinated by bees and birds; small, aromatic pollen
8.	Peanut	<i>Arachis hypogaea</i>	Fabaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Pollinated by insects; oval, smooth pollen grains
9.	Neem	<i>Azadirachta indica</i>	Meliaceae	Tree	Summer (May–July)	Arid regions, agricultural land	Sandy, loamy	Pollinated by bees; small, yellow pollen grains
10.	Bamboo	<i>Bambusa spp.</i>	Poaceae	Grass	Summer (June–August)	Tropical, subtropical areas	Loamy, moist	Wind-pollinated; pollen grains are light and winged
11.	Mustard	<i>Brassica juncea</i>	Brassicaceae	Herb	Spring (March–May)	Agricultural fields, roadsides	Loamy, sandy	Attracts bees and butterflies; small, yellow pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
12.	Cabbage	<i>Brassica oleracea</i>	Brassicaceae	Herb	Winter (November–March)	Agricultural fields, gardens	Loamy, fertile	Pollinated by bees; large, sticky pollen grains
13.	Cauliflower	<i>Brassica oleracea</i> var. <i>botrytis</i>	Brassicaceae	Herb	Winter (December–February)	Agricultural fields, gardens	Loamy, sandy	Bees pollinate; fine, spherical pollen grains
14.	Pigeon Pea	<i>Cajanus cajan</i>	Fabaceae	Shrub	Summer (June–September)	Agricultural fields	Loamy, well-drained	Attracts pollinators; small, rough pollen grains
15.	Wild Marigold	<i>Calendula arvensis</i>	Asteraceae	Herb	Winter–Spring (November–March)	Gardens, disturbed areas	Loamy, sandy	Pollinated by bees; large, yellow pollen grains
16.	Chili	<i>Capsicum annum</i>	Solanaceae	Herb	Summer (May–September)	Agricultural fields, gardens	Loamy, well-drained	Attracts bees and butterflies; smooth, rounded pollen grains
17.	Chili Pepper	<i>Capsicum annum</i>	Solanaceae	Herb	Summer (May–September)	Agricultural fields, gardens	Loamy, well-drained	Bees and butterflies pollinate; smooth, rounded pollen grains
18.	Papaya	<i>Carica papaya</i>	Caricaceae	Tree	Spring–Summer (March–July)	Tropical, subtropical areas	Loamy, fertile	Pollinated by flies and bees; large, sticky pollen grains
19.	Safflower	<i>Carthamus tinctorius</i>	Asteraceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Pollinated by bees; fine, yellow pollen grains
20.	Carob	<i>Ceratonia siliqua</i>	Fabaceae	Tree	Summer (June–August)	Mediterranean regions	Sandy, well-drained	Wind-pollinated; large, sticky pollen grains
21.	Chick-pea	<i>Cicer arietinum</i>	Fabaceae	Herb	Winter–Spring (October–March)	Agricultural fields, wastelands	Loamy, sandy	Pollinated by bees; small, rough pollen grains
22.	Chicory	<i>Cichorium intybus</i>	Asteraceae	Herb	Spring (March–June)	Roadsides, fields	Loamy, sandy	Pollinated by bees; smooth, blue pollen grains
23.	Citrus	<i>Citrus limon</i>	Rutaceae	Tree	Winter–Spring (Nov–May)	Tropical, subtropical regions	Sandy, loamy	Pollinated by bees; small, white to yellow pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
24.	Lemon	<i>Citrus limon</i>	Rutaceae	Tree	Winter–Spring (November–March)	Subtropical areas	Sandy, well-drained	Pollinated by bees; white, granular pollen grains
25.	Coriander	<i>Coriandrum sativum</i>	Apiaceae	Herb	Winter-Spring (Nov–March)	Agricultural fields, gardens	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
26.	Melon	<i>Cucumis melo</i>	Cucurbitaceae	Herb	Summer (May–August)	Agricultural fields	Loamy, fertile	Pollinated by bees; smooth, light pollen grains
27.	Cucumber	<i>Cucumis sativus</i>	Cucurbitaceae	Herb	Summer (May–August)	Agricultural fields	Loamy, sandy	Pollinated by bees; small, smooth pollen grains
28.	Cucumber	<i>Cucumis sativus</i>	Cucurbitaceae	Herb	Summer (June–August)	Agricultural fields, gardens	Loamy, fertile	Bees and butterflies pollinate; small, light pollen grains
29.	Turmeric	<i>Curcuma longa</i>	Zingiberaceae	Herb	Winter (November–April)	Tropical regions	Loamy, moist	Pollinated by bees; small, spherical pollen grains
30.	Artichoke	<i>Cynara cardunculus</i>	Asteraceae	Herb	Spring (March–May)	Gardens, agricultural fields	Loamy, sandy	Pollinated by bees; large, purple pollen grains
31.	Carrot	<i>Daucus carota</i>	Apiaceae	Herb	Spring–Summer (March–June)	Agricultural fields	Loamy, sandy	Pollinated by bees; small, white pollen grains
32.	Eucalyptus	<i>Eucalyptus globulus</i>	Myrtaceae	Tree	Spring (March–June)	Sandy soils, disturbed areas	Sandy, well-drained	Pollinated by wind; large, winged pollen grains
33.	Buckwheat	<i>Fagopyrum esculentum</i>	Polygonaceae	Herb	Summer (June–August)	Agricultural fields, disturbed areas	Well-drained soil	Pollinated by bees; small, rough pollen grains
34.	Ficus	<i>Ficus spp.</i>	Moraceae	Tree	Spring–Summer (April–July)	Tropical, subtropical areas	Loamy, sandy	Attracts bees and birds; smooth, round pollen grains
35.	Fennel	<i>Foeniculum vulgare</i>	Apiaceae	Herb	Summer (June–August)	Agricultural fields, roadsides	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
36.	Cotton	<i>Gossypium hirsutum</i>	Malvaceae	Herb	Summer (May–August)	Agricultural fields	Fertile, loamy	Attracts bees; large, sticky pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
37.	Sun-flower	<i>Helianthus annuus</i>	Asteraceae	Herb	Summer (June–August)	Agricultural fields	Loamy, fertile	Pollinated by bees; smooth, small pollen grains
38.	Sun-flower	<i>Helianthus annuus</i>	Asteraceae	Herb	Summer (June–August)	Agricultural fields, disturbed areas	Loamy, sandy	Pollinated by bees and birds; small, round pollen grains
39.	Barley	<i>Hordeum vulgare</i>	Poaceae	Herb	Spring–Summer (April–June)	Agricultural fields	Loamy, sandy	Pollinated by bees; small, smooth pollen grains
40.	Jasmine	<i>Jasminum officinale</i>	Oleaceae	Shrub	Spring–Summer (April–August)	Gardens, hedgerows	Loamy, fertile	Pollinated by bees; oval, smooth pollen grains
41.	Jatropha	<i>Jatropha curcas</i>	Euphorbiaceae	Shrub	Spring (March–June)	Arid regions, dry landscapes	Sandy, well-drained	Pollinated by bees; small, smooth pollen grains
42.	Lantana	<i>Lantana camara</i>	Verbenaceae	Shrub	Summer (May–October)	Roadsides, disturbed areas	Well-drained soil	Pollinated by flies and bees; large, sticky pollen grains
43.	Lavender	<i>Lavandula angustifolia</i>	Lamiaceae	Shrub	Summer (June–July)	Dry, well-drained areas	Sandy, well-drained	Pollinated by bees; small, rough pollen grains
44.	Lentil	<i>Lens culinaris</i>	Fabaceae	Herb	Winter (November–March)	Agricultural fields	Loamy, fertile	Bees pollinate; small, round pollen grains
45.	Cress	<i>Lepidium sativum</i>	Brassicaceae	Herb	Spring (March–May)	Gardens, agricultural fields	Loamy, sandy	Attracts bees for pollination; small, spherical pollen grains
46.	Cress	<i>Lepidium sativum</i>	Brassicaceae	Herb	Spring (March–May)	Gardens, agricultural fields	Loamy, sandy	Pollinated by bees; smooth, rounded pollen grains
47.	Mango	<i>Mangifera indica</i>	Anacardiaceae	Tree	Spring (March–May)	Tropical, subtropical regions	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
48.	Maranta	<i>Maranta arundinacea</i>	Marantaceae	Herb	Spring (March–June)	Wetland areas, tropical regions	Loamy, moist	Pollinated by bees; large, yellow pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
49.	Mint	<i>Mentha spp.</i>	Lamiaceae	Herb	Spring–Summer (March–June)	Gardens, fields	Loamy, moist	Pollinated by bees; smooth, round pollen grains
50.	Bitter Gourd	<i>Momordica charantia</i>	Cucurbitaceae	Herb	Summer (May–September)	Agricultural fields, gardens	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
51.	Moringa	<i>Moringa oleifera</i>	Moringaceae	Tree	Spring–Summer (March–July)	Dry, arid regions	Sandy, loamy	Attracts bees; aromatic, small pollen grains
52.	Tobacco	<i>Nicotiana tabacum</i>	Solanaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Pollinated by bees; smooth, aromatic pollen grains
53.	Basil	<i>Ocimum basilicum</i>	Lamiaceae	Herb	Summer (June–August)	Gardens, agricultural fields	Loamy, fertile	Pollinated by bees; small, white pollen grains
54.	Sweet Basil	<i>Ocimum basilicum</i>	Lamiaceae	Herb	Summer (June–August)	Gardens, agricultural fields	Loamy, fertile	Pollinated by bees; small, white pollen grains
55.	Olive	<i>Olea europaea</i>	Oleaceae	Tree	Spring (March–May)	Dry regions, hillsides	Rocky, well-drained	Pollinated by bees; small, round pollen grains
56.	Oregano	<i>Origanum vulgare</i>	Lamiaceae	Herb	Summer (June–August)	Dry, rocky areas	Well-drained soil	Pollinated by bees and birds; smooth, sticky pollen grains
57.	Date Palm	<i>Phoenix dactylifera</i>	Arecaceae	Tree	Spring (March–May)	Desert regions, oases	Sandy, saline	Pollinated by bees; smooth, fine pollen grains
58.	Almond	<i>Prunus dulcis</i>	Rosaceae	Tree	Spring (March–May)	Dry, temperate regions	Sandy, loamy	Pollinated by bees and birds; smooth, small pollen grains
59.	Guava	<i>Psidium guajava</i>	Myrtaceae	Tree	Spring (March–May)	Tropical, subtropical areas	Loamy, sandy	Pollinated by bees and birds; smooth, sticky pollen grains
60.	Pomegranate	<i>Punica granatum</i>	Lythraceae	Shrub/Tree	Spring (March–May)	Dry, arid regions	Sandy, well-drained	Pollinated by flies; small, round pollen grains
61.	Radish	<i>Raphanus sativus</i>	Brassicaceae	Herb	Spring (March–May)	Agricultural fields	Loamy, sandy	Pollinated by bees; small, smooth pollen grains
62.	Rosemary	<i>Rosmarinus officinalis</i>	Lamiaceae	Shrub	Spring (April–June)	Gardens, fields	Well-drained soil	Pollinated by bees; small, smooth pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
63.	Sage	<i>Salvia officinalis</i>	Lamiaceae	Shrub	Spring–Summer (April–June)	Gardens, fields	Loamy, fertile	Pollinated by bees; large, smooth pollen grains
64.	Sesame	<i>Sesamum indicum</i>	Pedaliaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, fertile	Pollinated by bees; large, purple pollen grains
65.	Sesame	<i>Sesamum indicum</i>	Pedaliaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Pollinated by bees; smooth, round pollen grains
66.	Tomato	<i>Solanum lycopersicum</i>	Solanaceae	Herb	Summer (June–August)	Agricultural fields, gardens	Loamy, fertile	Pollinated by bees; smooth, small pollen grains
67.	Aubergine	<i>Solanum melongena</i>	Solanaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, sandy	Pollinated by bees; small, round pollen grains
68.	Spinach	<i>Spinacia oleracea</i>	Amaranthaceae	Herb	Winter (November–March)	Agricultural fields	Loamy, fertile	Pollinated by bees; small, rough pollen grains
69.	Mari-gold	<i>Tagetes erecta</i>	Asteraceae	Herb	Summer (April–August)	Gardens, agricultural fields	Loamy, fertile	Pollinated by bees; small, yellow pollen grains
70.	Tamarind	<i>Tamarindus indica</i>	Fabaceae	Tree	Winter–Spring (December–March)	Tropical, subtropical areas	Sandy, well-drained	Pollinated by bees; small, rough pollen grains
71.	Thyme	<i>Thymus vulgaris</i>	Lamiaceae	Shrub	Spring (April–June)	Dry, rocky areas	Well-drained soil	Pollinated by bees and flies; smooth, large pollen grains
72.	Thyme	<i>Thymus vulgaris</i>	Lamiaceae	Shrub	Spring (April–June)	Dry, rocky areas	Well-drained soil	Pollinated by bees; small, light pollen grains
73.	Fenu-greek	<i>Trigonella foenum-graecum</i>	Fabaceae	Herb	Winter (November–March)	Agricultural fields	Loamy, sandy	Wind-pollinated; large, winged pollen grains
74.	Fenu-greek	<i>Trigonella foenum-graecum</i>	Fabaceae	Herb	Winter (November–March)	Agricultural fields, wastelands	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
75.	Wheat	<i>Triticum aestivum</i>	Poaceae	Herb	Spring–Summer (March–July)	Agricultural fields	Loamy, fertile	Pollinated by bees; small, light pollen grains

S. No.	Common Name	Botanical Name	Family	Life-form	Flowering Period	Ecology	Soil Type	Plant insect interactions/pollen grains
76.	Violet	<i>Viola spp.</i>	Violaceae	Herb	Spring (March–May)	Gardens, forests	Loamy, moist	Pollinated by bees; small, aromatic pollen grains
77.	Sweet Corn	<i>Zea mays</i>	Poaceae	Herb	Summer (June–August)	Agricultural fields	Loamy, fertile	Pollinated by bees; small, rough pollen grains
78.	Ginger	<i>Zingiber officinale</i>	Zingiberaceae	Herb	Winter–Spring (November–April)	Agricultural fields, gardens	Loamy, sandy	Pollinated by bees; small, aromatic pollen grains
79.	Jujube	<i>Ziziphus jujuba</i>	Rhamnaceae	Tree	Spring (March–May)	Arid regions, dry forests	Sandy, loamy	Pollinated by bees; small, round pollen grains

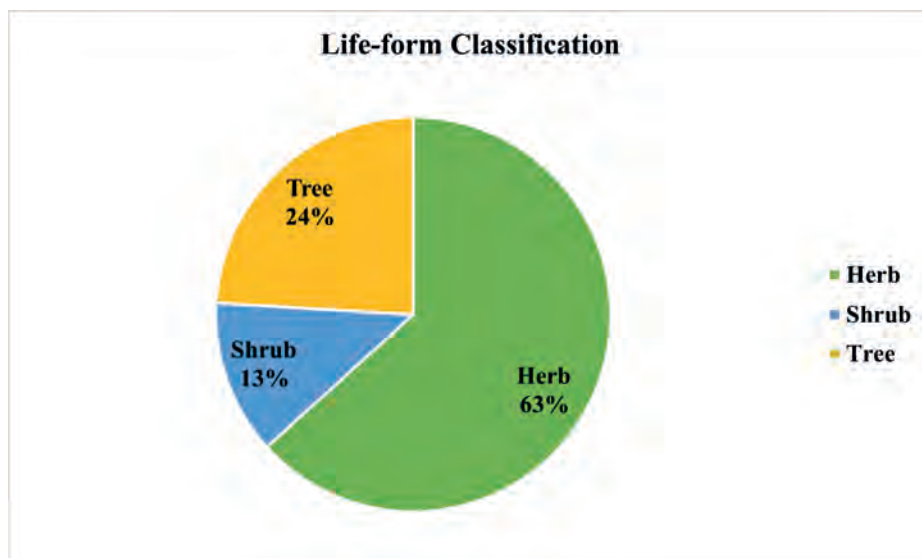


Figure 1. Habit of entomological floral diversity in District Mianwali.

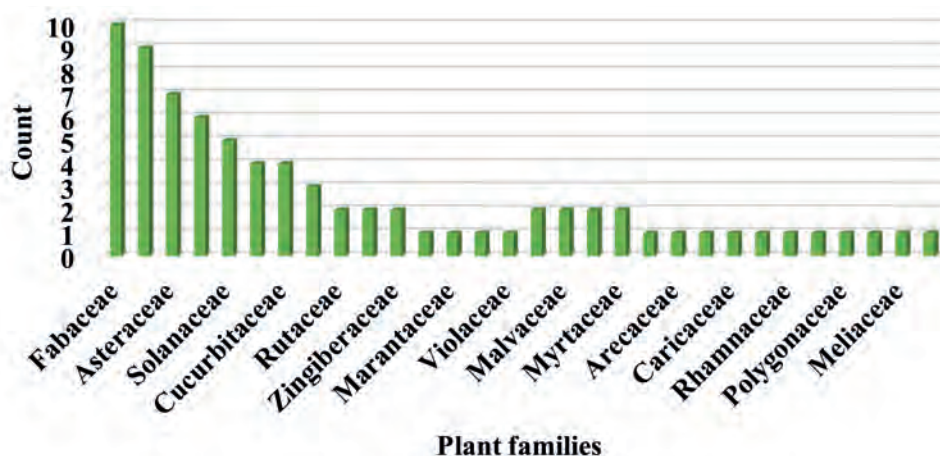


Figure 2. Botanical families illustrated of entomological flora.

A visual presentation illustrates the widespread occurrence of plant families in Mianwali district. The Fabaceae family is the most common, with ten identified species, followed by

Lamiaceae with nine species, Asteraceae with seven species, and Brassicaceae with six species. These plant families have ecological value and support insect pollinators, as shown in Figure 2. The Solanaceae, Poaceae, and Cucurbitaceae families also contribute to the diverse plant life in the region. A smaller number of floral species are found in the Apiaceae, Rutaceae, Pedaliaceae, and Zingiberaceae families.

Mianwali features plant diversity which expands through the combined presence of Malvaceae, Oleaceae, Myrtaceae, and Amaryllidaceae families along with their 2 Mianwali features a diverse range of plant species, including representatives from the Malvaceae, Oleaceae, Myrtaceae, and Amaryllidaceae families. Moringaceae, Arecaceae, Asphodelaceae, and Rosaceae are also present in the region, but in limited numbers due to their restricted geographical distribution. The environmental conditions in Mianwali play a crucial role in the growth of entomophilous plant species, with soil types being a key factor.

Among the observed soil types in Mianwali, a combination of loamy and sandy soil is the most common, occurring 17 times, followed by loamy and fertile soil, which occurs 14 times. These soil types provide the perfect balance of texture, structure, drainage, and nutrient retention properties that benefit the growth of entomophilous plant species.

Nine occurrences of well-drained sandy soil indicate the presence of plants adapted to dry and porous conditions. The region also exhibits significant soil characteristics, including loamy and well-drained soil (4 occurrences), loamy and moist soil (4 occurrences), and sandy and loamy soil (4 occurrences). Additionally, sandy soils with salt content have been recorded three times in different areas, suggesting the presence of salt-tolerant plant species in these regions. The presence of well-drained soil further highlights the importance of proper drainage for plant sustainability.

Plant species primarily adapted to desert

regions through the development of xerophytic leaves together with deep root networks and drought survival features. Though the arid and semi-arid regions were dominated by date palm (*Phoenix dactylifera*) and acacia (*Acacia tortilis*) and tamarind (*Tamarindus indica*), fennel (*Foeniculum vulgare*) and basil took control of cultivated areas and farm plots. The majority of plants showed winter-spring flowering behaviors during the period of November through March due to improved water availability during this cooler time of year. The hotter summer months resulted in specific flowering periods for chilli (*Capsicum annuum*) and okra (*Abelmoschus esculentus*) among other plant species.

3.2 Insect Pollinator Interactions

The main insect interactions occurred between pollinators who visited floral species. During the blooming season of mustard (*Brassica juncea*) and coriander and basil species honeybees (*Apis mellifera*), butterflies (*Danaus chrysippus*) and moths demonstrated elevated activity patterns. The presence of various pollinators on these plants signifies a mutualistic connection because they distributed pollen leading to cross-pollination among them. The insect group consisting of aphids and caterpillars was observed consuming multiple agricultural plants and natural vegetation. The presence of aphids on chickpea plants severely reduced plant growth while diminishing their productive yield amounts. Plants of cabbage (*Brassica oleracea*) suffered defoliation damage from caterpillars that produced substantial negative effects on their useful yield. Natural predators including ladybugs from the family Coccinellidae and spiders from Araneidae family controlled the herbivore population numbers. The results of soil analysis showed that agricultural land contained loamy fertile soils which enabled increased plant diversity and greater abundance of insect species. The habitat of wild areas with saline and sandy ground exhibited lower plant diversity yet the existing tamarind and acacia species adapted successfully to these conditions which sustained specialized insect groups.

3.3 Pollination and Ecological Significance

The role of pollinators in maintaining the floral diversity of the region was crucial. Crops like melon (*Cucumis melo*), tomato (*Solanum lycopersicum*), and sunflower (*Helianthus annuus*) were observed to have higher fruiting success when pollinators were active. This suggests the importance of maintaining pollinator populations for enhancing crop yields and promoting sustainable agriculture.

In contrast, the relationship between herbivores and their host plants seemed more parasitic, leading to decreased plant fitness. Effective pest management strategies that encourage natural predator populations could help mitigate the damage caused by herbivorous insects.

4. Discussion

The entomological diversity associated with the flora of District Mianwali plays a pivotal role in maintaining ecological stability, particularly through the crucial process of pollination. The region's flora consists of a mixture of xerophytic species and cultivated crops, providing diverse habitats for a range of pollinators, including honeybees (*Apis mellifera*), butterflies (e.g., *Danaus chrysippus*), and other solitary bees. Pollinators were most abundant during the flowering periods of herbs such as coriander (*Coriandrum sativum*), basil (*Ocimum basilicum*), and mustard (*Brassica juncea*), which are known to attract a variety of insect species. The mutualistic interactions between the plants and their pollinators are vital for the reproductive success of the species, supporting crop yields and biodiversity in the region (Patil et al., 2024). The plant-insect relationships also ensure the persistence of key plant species within the arid ecosystem that are adapted to the region's climatic conditions (Saunders et al., 2023).

In contrast to the positive effects of pollinators, the region also experiences significant pressure from herbivorous insects, which impact the overall health and productivity of the flora (Raderschall et al., 2021). Crops such as chickpea (*Cicer arietinum*) and cabbage (*Brassica oleracea*) suffer from aphid infestations, which can cause significant damage to plant

tissues and reduce crop yield (Sarwar, 2017). The herbivorous insects observed in Mianwali, including various species of aphids and caterpillars, often lead to defoliation and stunted growth of plants. Interestingly, natural predators, such as ladybugs (*Coccinellidae*) and spiders (*Araneidae*), help regulate the herbivore populations and mitigate their impact on plant health. This reflects the importance of preserving the natural predator-prey dynamics within agricultural ecosystems to maintain pest control naturally (Altieri, 1999). Furthermore, promoting biodiversity within the agro-ecosystem can reduce reliance on chemical pesticides, fostering more sustainable agricultural practices (Yadav & Kumar, 2021).

The relationship between plant diversity and entomological interactions in the arid zone of Mianwali emphasizes the interconnectedness of ecosystem components. The distinct plant species found in the region exhibit a range of adaptations to the harsh climatic conditions, from drought-resistant characteristics to specialized flower morphologies that cater to specific pollinators. The diversity of plant species in turn supports a variety of insect species, each contributing to ecosystem processes such as nutrient cycling, pest control, and pollination (Upadhyay et al., 2025). As demonstrated by the flowering period of species like tamarind (*Tamarindus indica*) and date palm (*Phoenix dactylifera*), which thrive in the dry, arid landscape, the entomological diversity observed in the habitats is a direct reflection of plant adaptations to the environment (Krueger, 2021). This signifies the need for conservation strategies that not only focus on plant species but also protect and promote the insect communities that contribute to the sustainability of the ecosystems (Chowdhury et al., 2023). Thus, complex plant-insect dynamics is essential for effective conservation and management of biodiversity in arid regions.

Conclusion

The floristic and entomological diversity of the arid zone in District Mianwali reveals a complex interplay between plants and insects. The region supports a variety of species that

are adapted to arid conditions, with notable interactions between pollinators and flowering plants that support agricultural productivity. Implementing effective pest management strategies, along with sustainable agricultural practices, could enhance plant-insect interactions and improve ecological balance. Future research should prioritize long-term monitoring

of these interactions to develop effective conservation strategies for maintaining biodiversity in arid ecosystems.

Conflict of Interest

The authors declare no conflicts of interest.

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OLD CEMETERIES AS REFUGE OF THE STEPPE FLORA IN THE RIGHT-BANK DNIPRO GRASS STEPPE DISTRICT (SOUTHERN UKRAINE)

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Abstract. *Changes in natural landscapes and economic activities lead to the loss of a large proportion of the steppes, especially in Ukraine. Recent studies have demonstrated the high importance of cultural heritage sites, includes with old cemeteries. Over the past centuries, most of the steppes we studied have been converted to cropland, but the cultural importance of the old cemeteries may have helped prevent their destruction through ploughing. We investigated floristic composition of 50 old cemeteries in various urban landscape of southern Ukraine. The area of the old cemeteries varies from 0.3 ha to 32.5 ha. The floristic composition includes 684 species belonging to 356 genera, 81 families, 4 classes and 2 divisions. The total number of species within cemetery varied from 82 to 236 (on average 171 species). The flora of old cemeteries is species-rich, including protected and native, steppe and non-synanthropic species. We recorded 64 protected vascular plant species in the studied old cemeteries, which represents 9.2 % of the total species pool. Our records show that old cemeteries act as hot-spots for biodiversity: the high number of protected, steppes (40.2%) and non-synanthropic species (36.55%) in the floristic composition indicates a good level of preservation of steppes at the old cemeteries in southern Ukraine.*

Keywords: *biodiversity, steppe, cultural heritage sites, vascular plants, flora, protected species.*

Introduction

Anthropogenic activities have led to a significant loss of natural habitats in the world over the last few centuries (Löki et al., 2019a) and in Ukraine (Burkovskyi et al., 2013). Grand-scale destruction of steppe ecosystems carried in the Soviet era in Ukraine and about all plain steppes were tilled, where the area of steppe vegetation has decreased by a factor of 40 (in the XX century the steppe covered about 40% of the total territory of the country (Kotorchenko & Peregrym, 2012), while today steppe remnants have survived on only 1% of this territory) (Burkovskyi et al., 2013).

Steppe flora is preserved mainly in protected

areas, ravines, gullies, river terraces and sea cliffs (usually due to steep slopes, which make ploughing with agricultural machinery impossible) (Burkovskyi et al., 2013). Cultural heritage sites (Löki et al., 2019a), such as burial mounds (kurgans) (Deak et al., 2016, 2018, 2020, 2021; Dembicz et al., 2020; Sudnik-Wójcikowska & Moysiienko, 2006, 2010, Sudnik-Wójcikowska et al., 2012; Moysiienko & Sudnik-Wójcikowska 2006, 2009; Moysiienko et al., 2014, 2022; Valkó et al., 2018), old settlements (Celka, 2011; Dayneko et al., 2020; Moysiienko et al., 2015, 2018; 2019; 2020) and old cemeteries (Barrett & Barrett, 2001; Galera et al., 1993; Lisowska et al., 1994; Löki et al., 2019a,b; Moysiienko et al.,

2017; 2021; Nowińska et al., 2019, 2020; Skobel & Moysiienko, 2022; Skobel et al., 2023; Skobel et al. 2025; Vickery et al., 2009). In the steppe zone of Ukraine, cultural heritage as kurgans and ancient settlements (Dayneko et al., 2020; Moysiienko et al., 2022) sites frequently represent are the one of the last refuges of steppe vegetation in eastern Europe, where intensive landscaping and agriculture have largely eliminated most of the natural steppe vegetation.

Despite their significance for biodiversity preservation, old cemeteries have not been subjected to a survey in Ukraine before. In our study, we consider old cemeteries as cultural heritage sites established more than 100 years ago on (or near) a steppe habitat (Moysiienko et al., 2021). In our previous research we found that the presence of typical steppe species such as *Festuca valesiaca* agg, *Koeleria macrantha*, *Stipa capillata* and a high proportion of Non-synanthropic and protected species compared to invasive species indicates a comparatively high degree of preservation of steppe flora in its natural state in the old cemeteries (Moysiienko et al., 2021; Skobel & Moysiienko, 2022).

Therefore, in this study we asked: How high is the species richness, of vascular plants on old cemeteries located in Right-Bank Dnipro Grass Steppe District of Southern Ukraine and provide insight on their threats and significance of their active conservation and recommendation for their preservation and management.

To achieve this goals, we plan to research the flora of 50 old cemeteries located within the Right-Bank of Dnipro Grass Steppe District.

Materials and Methods

The study of the flora's old cemeteries has been the subject of our in-depth research. Our research based on previously unprocessed materials 2007-2017 (Moysiienko et al., 2022), our

materials 2020-2022 (Skobel, 2022) and 2023-2024 (Skobel et al., 2025). We have searched for old cemeteries in the bibliographical sources and open sources for research. The Right-Bank of Dnipro Grass Steppe District according to the Geobotanical zoning of Ukraine and adjacent areas (Didukh & Sosonko, 2003) belongs to the Pontic Region of Ukraine (Figure 1, Figure 2, Table 1). The territory includes parts of territories of the Dnipopetrovsk, Kherson, Mykolaiv and Odesa administrative Regions (47.96-44.80° N, 34.80-28.96 °E) (Skobel et al., 2025).

The climate of steppe physiognomy is continental and is characterized by a snow less winters and hot, dry summers (Mordkovich 2014). The Right-Bank of Dnipro Grass Steppe District is characterized by low precipitation, which is reduced from north to south and west to east (400-450 mm per year) (Marynych & Shyshchenko 2005). The average annual temperature in the Right-Bank of Dnipro Grass Steppe District values in question exhibit a north-south gradient, with higher values observed in the southern regions and lower values in the northern regions (11.7⁰-8.4⁰C) (Karger et al. 2017). Average summer temperature +30⁰C, average winter temperature - no more than +4⁰C (Karger et al. 2017) with extreme temperatures of +40⁰C in summer and -28⁰C in winter (Karger et al. 2017). Soil resources of the Right-Bank of Dnipro Grass Steppe District are represented by normal and southern chernozems and dark kastanozems in the southeast (Marynych & Shyshchenko 2005; National Atlas, 2007).

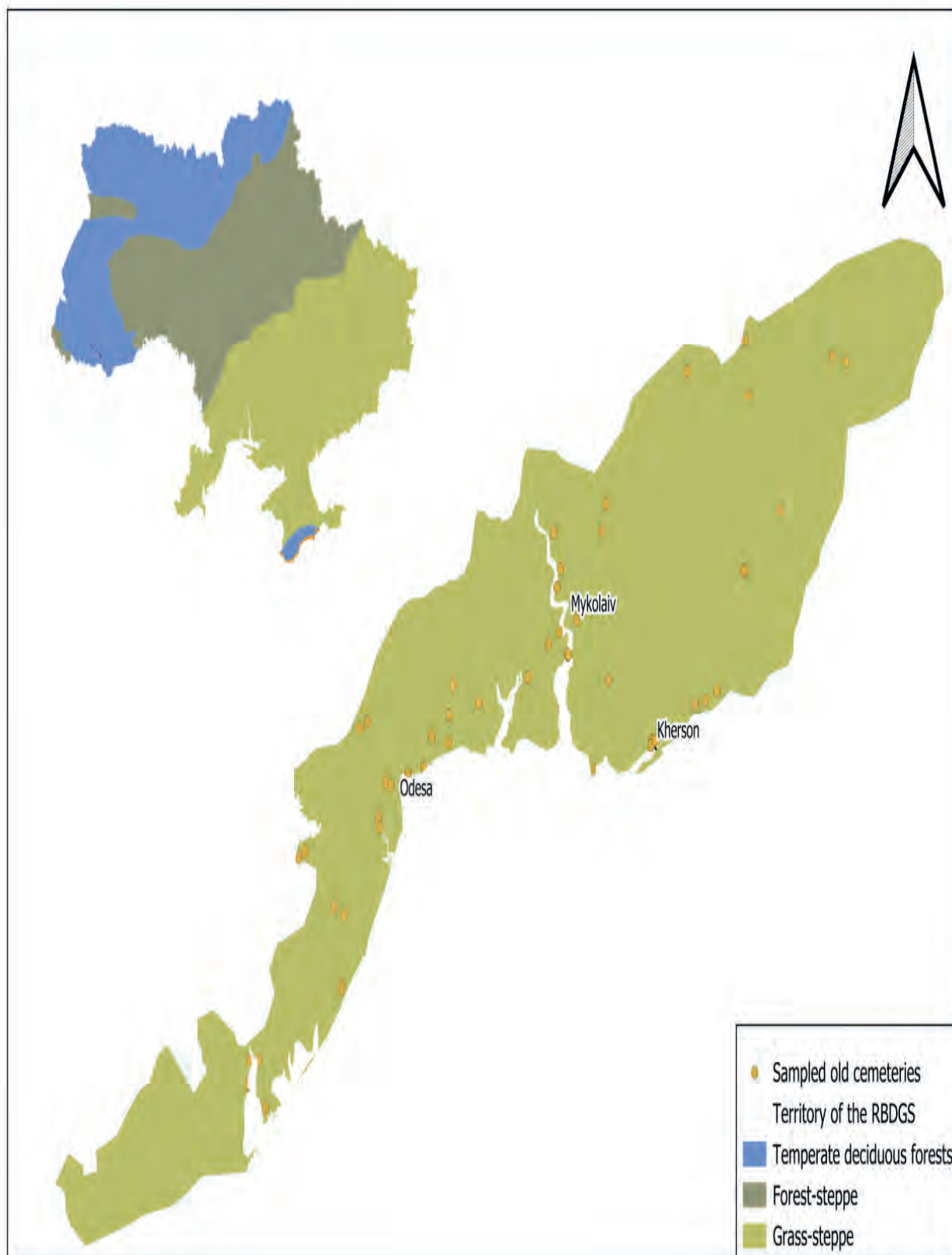


Figure 1. Map of Ukraine according to climatic definitions of the world's terrestrial biomes (Loidi et al., 2022) and vector map (Loidi et al., 2023), with the study area - Right-Bank of Dniro Grass Steppe District, country border, extracted from OpenStreetMap (openstreetmap.org).



Figure 2. General view of old cemeteries of the Right-Bank of Dnipro Grass Steppe District. A -Chervonyi Tik; B -Khrystoforivka; C - Libopil; D -Lymany; E -Shestirnia; F - Sebyne. Photos by N. Skobel

Table 1

**Description of the studied old cemeteries studied of the Right-Bank of
Dnipro Grass Steppe District**

№	Site lation	Region (Oblast)	Latitude	Longitude	The establishment date of the village(*-date of the earliest probable burial)	Area (ha)
1	Balovne	Mykolaiv	47.053753	31.889975	1684	2.29
2	Borysivka	Odesa	45.792525	29.637213	1860th	2
3	Buldynka	Odesa	46.662591	30.970278	1803	1.88
4	Cemetery near Kurgan Balakshova	Kherson	47.098420	33.253836	1855-1865	0.67
5	Cemetery Za-balkivske	Kherson	46.636648	32.582764	1870th	9.75
6	Chervonyi Tik	Dnipropetrovsk	47.660932	33.910625	1927	1.5
7	Ekonomiia Ivanivka	Kherson	47.097128	33.273068	1822	2.21
8	Fedorivka	Mykolaiv	46.749047	31.316719	1800	1.32
9	Hlyboke	Odesa	45.727587	29.619549	1841	2.73
10	Inhulka	Mykolaiv	47.200287	32.217219	1802	4.26
11	Jewish cemetery c. Bilhorod-Dnistrovskyi	Odesa	46.183482	30.325645	1855-1865	0.35
12	Jewish cemetery c. Kherson	Kherson	46.648517	32.586413	1860th	2.82
13	Kamianka	Mykolaiv	46.815796	31.684462	1790	2.41
14	Kherson Memorial Cemetery	Kherson	46.649444	32.613333	1780h	15.6
15	Khrystoforivka	Mykolaiv	47.273123	32.252789	1799	1.2
16	Korolivske	Mykolaiv	46.9031754	31.8269422	1926 (*1860th)	0.31
17	Kosivka	Odesa	45.9936980	30.3117668	1834	0.7
18	Kostiantynivka	Mykolaiv	47.102464	31.915738	1783	2.46
19	Kozatske	Odesa	46.354418	30.044033	1774	3.14
20	Kryzhanivka	Odesa	46.559707	30.797625	1775	0.75
21	Liubopil	Odesa	46.717086	31.100161	1886	1.88
22	Lymany	Odesa	45.6622759	29.7507285	1812	3.62
23	Mykolaivskyi Nekropol	Mykolaiv	46.967107	32.034375	1795	32.5
24	Nerubaiske	Odesa	46.536969	30.632117	1795	4.67
25	Nova Dofynivka	Odesa	46.575880	30.912262	1860th	3.83
26	Novobohdanivka (big cemetery)	Mykolaiv	46.874752	31.972625	1865	1.47
27	Novobohdanivka (small cemetery)	Mykolaiv	46.876910	31.973002	1920th	0.7
28	Odradove	Odesa	46.681123	30.443640	1637	0.87

No	Site lation	Region (Oblast)	Latitude	Longitude	The establishment date of the village(*-date of the earliest probable burial)	Area (ha)
29	Poniativka	Kherson	46.743071	32.903220	1780	1.1
30	Popazdra	Odesa	45.985272	30.307722	1824	0.81
31	Posad- Pokrovske	Kherson	46.807617	32.271652	1789	3.48
32	Prylymanske	Odesa	46.4166959	30.5856383	1793	0.17
33	Pshonianove	Odesa	46.796467	31.127069	1850	0.1
34	Sebyne	Mykolaiv	47.197869	31.867054	1792	0.89
35	Shestirnia	Dnipropet-rovsk	47.555680	33.290566	1689	2.25
36	Shyroke	Dnipropet-rovsk	47.7005443	33.2725594	1787	8.94
37	Skobelev	Mykolaiv	47.620095	32.847386	1875	1.55
38	Stanislav	Kherson	46.572933	32.150254	1697	6.8
39	Starokozachie	Odesa	46.336391	29.998868	1824	3.48
40	Sychavka	Odesa	46.644083	31.095152	1801	1.95
41	Tiahynka	Kherson	46.780492	33.062809	1778	7
42	Tokarivka	Kherson	46.754950	32.974147	1780	2.6
43	Trapivka	Odesa	45.791889	29.703639	1829	2.12
44	Tryfonivka	Kherson	47.257042	33.524622	1863	3.27
45	Usatove	Odesa	46.528096	30.670819	1775	8.4
46	Ust-Kamianka	Dnipropet-rovsk	47.644582	34.011166	1754	0.58
47	Velyka Korenykha	Mykolaiv	46.936568	31.907024	1860th	0.34
48	Velykyi Dalnyk	Odesa	46.445883	30.579972	1795	2.72
49	Vypasne	Odesa	46.203091	30.256395	1795	1.32
50	Yelysavetivka	Odesa	46.697052	30.501878	1856	0.45

The selection of old cemeteries in 2023-2024 for the research was based on ongoing materials from the Google map "Ancient Cemeteries of Ukraine" (Ukraine Incognita, 2024) and biographic data on the dates of foundation of human settlement community and cartographic materials (History of villages of the Ukrainian SSR, 1953, Schubert Maps, 1965). The area and boundaries of the old cemeteries were determined using Google Earth and include the entire area of the old cemeteries, including the area of new burials if the old cemetery was extended (Google Earth, 2024). For details on the studied old cemeteries, i.e. coordinates, area, age, see Table 1.

We carried out a visual analysis based on satellite images, with particular emphasis on the selection of cemeteries that were not overgrown and not covered with phanerophytes. In order to carry out a study of the flora of the area in question and the presence of steppe refuge in the old cemeteries, we followed the next criteria, which could only be checked in the field.

- Presence of protected species (Red list of Dnipropetrovsk Region, 2011; Red list of Kherson Region, 2013; Red list of Mykolaiv Region, 2012; Red list of Odesa Region, 2011), Red Data Book of Ukraine (Didukh, 2009), etc.
- Presence of bunch-grasses (or tussock

grasses such as *Festuca*, *Koeleria*, *Stipa* etc.) and other steppe species (i.e. species attaining optimum growth in the plant communities of the syntaxonomic class or order: *Festuco-Brometea*, *Festucetea vaginatae*, *Galietalia veri* and *Polygono-Artemisietea* (Mucina et al., 2016).

- High proportion of native species in comparison to alien species (Protopova, 1991; Vynokurov et al., 2024).

We classified each species as a “steppe” or “non-steppe” species and assigned it to the appropriate group of the historical-geographical classification scheme according to Kornaś (1981), : native species including non-synanthropic species – natives occurring exclusively in natural or semi-natural vegetation; apophytes – natives associated with anthropogenic habitats; hemiapophytes – natives associated with natural and anthropogenic (mostly semi-natural) habitats; alien species including archaeophytes – arrived in Europe before the year 1500 (Protopova 1991; Vynokurov et al., 2024); kenophytes – introduced after the year 1500 (Protopova 1991; Vynokurov et al., 2024). Both groups are permanently established, in contrast to ergasiophytes – cultivated aliens escaping from cultivation and appearing temporarily (Protopova 1991; Protopopova & Shevera 2014, Vynokurov et al., 2024; Skobel et al., 2025). The abundance of each species on each old cemetery was assessed using an authors 5-point scale: I – rare, II – relatively rare, III – not rare, IV – relatively frequent, V – common.

In total we inventoried floristic composition of 50 old cemeteries. Each old cemetery was investigated 3 times during the growing season: in spring, summer, and autumn. The list of flora includes spontaneous species of vascular plants and species that have escaped from cultivating. The nomenclature of the data set is as follows: “Ukrainian Plant Trait Database: UkrTrait v. 1.0” - (Vynokurov et al., 2024) for species not presented in checklist, mostly for ergasiophytes - “Plants of the World Online” (POWO, 2024).

The data sets published in the open-access data base Global Biodiversity Information Facility - GBIF (Skobel et al., 2022; Skobel et al., 2024).

Results

684 vascular plant species were recorded in the flora of 50 old cemeteries (Moysiyenko et al., 2021, Skobel et al., 2022; Skobel et al., 2024, Skobel et al., 2025), belongs to 356 genera, 81 families, 4 classes and 2 divisions. Total species richness ranged from 84 (Pshonianove) to 242 (Nerubaiske). The mean number of vascular plant species per old cemetery was 174. The flora of the investigated old cemeteries represents 13.5 % of the flora of Ukraine, which includes 5100 species (Mosyakin & Fedoronchuk, 1999), 33.9% of the flora of Northern Black Sea Region, which includes 2025 species (Moysiyenko 2013), 75.1% Right-Bank Dnipro Grass Steppe District, which includes 916 species (Krytskaya, 1985). A majority of 61.4 % (420 species) of all species that occurred on the old cemeteries were native plants. Non-synanthropic plants occurring with the highest frequency were: *Asparagus officinalis*, *Centaurea borysthena*, *Cephalaria uralensis*, *Convallaria majalis*, *Euphorbia seguieriana*, *Iris pumila*, *Kochia prostrata*, *Muscari neglectum*, *Paeonia tenuifolia*, *Phlomis tuberosa*, *Potentilla semilaciniosa*, *Salsola tragus*, *Sedum acre*, *Tanacetum millefolium*, *Viola ambigua*. More than half of this group (i.e. 250 species) and 36.55 % of the total number of species were non-synanthropic plants, represented on the old cemeteries mostly by steppe plants (i.e. 278 species) and 40.2 %. It should be noted that non-synanthropic species include not only steppe species, but also those originating from moist and forest habitats (these species were sometimes noted on old cemeteries).

The flora of old cemeteries is comparable to the flora of kurgans (Moysiyenko et al., 2014) and ancient settlements (Dayneko 2020) in terms of the shares of non-synanthropic and native species and somewhat poorer in terms of the shares of steppe species.

A less part of majority 38.6% (264 species) of all species that occurred on the old cemeteries were alien plant. The most of species are kenophytes 27.5% (188 species), less part represent archaophytes 11.1 % (76 species). Kenophytes plants occurring with the highest frequency were: *Bromus squarrosus*, *Cardaria draba*, *Coryza canadensis*, *Centaurea diffusa*, *Ambrosia artemisiifolia*, *Syringa vulgaris*, *Ailanthus altissima*, *Amaranthus retroflexus*, *Psephellus dealbatus*, *Sedum rupestre*, *Arabidopsis thaliana*, *Reseda lutea*, *Tribulus terrestris*, *Acer negundo*, *Amaranthus cruentus*, *Eragrostis minor*, *Acer platanoides*, *Amaranthus blitoides*, *Cerasus vulgaris*, *Iris × hybrida*, *Sisymbrium altissimum*, *Parthenocissus quinquefolia*, *Rumex patientia*, *Hemerocallis fulva*, *Grindelia squarrosa*. Archaophytes plants occurring with the highest frequency were: *Anisantha tectorum*, *Buglossoides arvensis*, *Capsella bursa-pastoris*, *Ballota nigra*, *Veronica arvensis*, *Portulaca oleracea*, *Lamium amplexicaule*, *Setaria viridis*, *Anisantha sterilis*, *Descurainia sophia*, *Artemisia absinthium*, *Cichorium intybus*, *Lactuca serriola*,

Veronica polita.

Significant part of alien flora at the old cemeteries present ergasiophygophytes – cultivated aliens escaping from cultivation and appearing temporarily 19 % (130 species). Ergasiophygophytes plants occurring with the highest frequency were: *Acer negundo*, *Acer platanoides*, *Alcea rosea*, *Ailanthus altissima*, *Armeniaca vulgaris*, *Amaranthus cruentus*, *Cerasus vulgaris*, *Gaillardia pulchella*, *Hemerocallis fulva*, *Iris × hybrida*, *Juglans regia*, *Lycium barbarum*, *Morus alba*, *Psephellus dealbatus*, *Prunus cerasifera*, *Robinia pseudoacacia*, *Sedum rupestre*, *Sedum spurium*, *Syringa vulgaris*, *Ulmus pumila*, *Vinca minor*. Non-stable part of the floristic composition, belongs to ergasiophygophytes on the old cemeteries. The flora of old cemeteries is comparable to the flora of kurgans (Moysiyenko et al., 2014) and ancient settlements (Dayneko 2020) in terms of the shares of alien species and somewhat higher. It is indicate a specific characteristics of the floristic composition on old cemeteries.

Table 2

Number and percentage of particular groups of vascular plant species of old cemeteries

Characteristics of the flora of old cemeteries investigated	Total of 50 old cemeteries (40.52 ha)	
	No.	%
Total number of species	684	100.0
Steppe species	278	40.2
Native species	420	61.4
Non-synantropic species	250	36.55
Aliens established before A.D. 1 500 (archaeophytes)	76	11.1
Newcomers, aliens established after A.D. 1 500 (kenophytes)	188	27.5
Ergasipohytes	130	19
Protected species	65	9.2

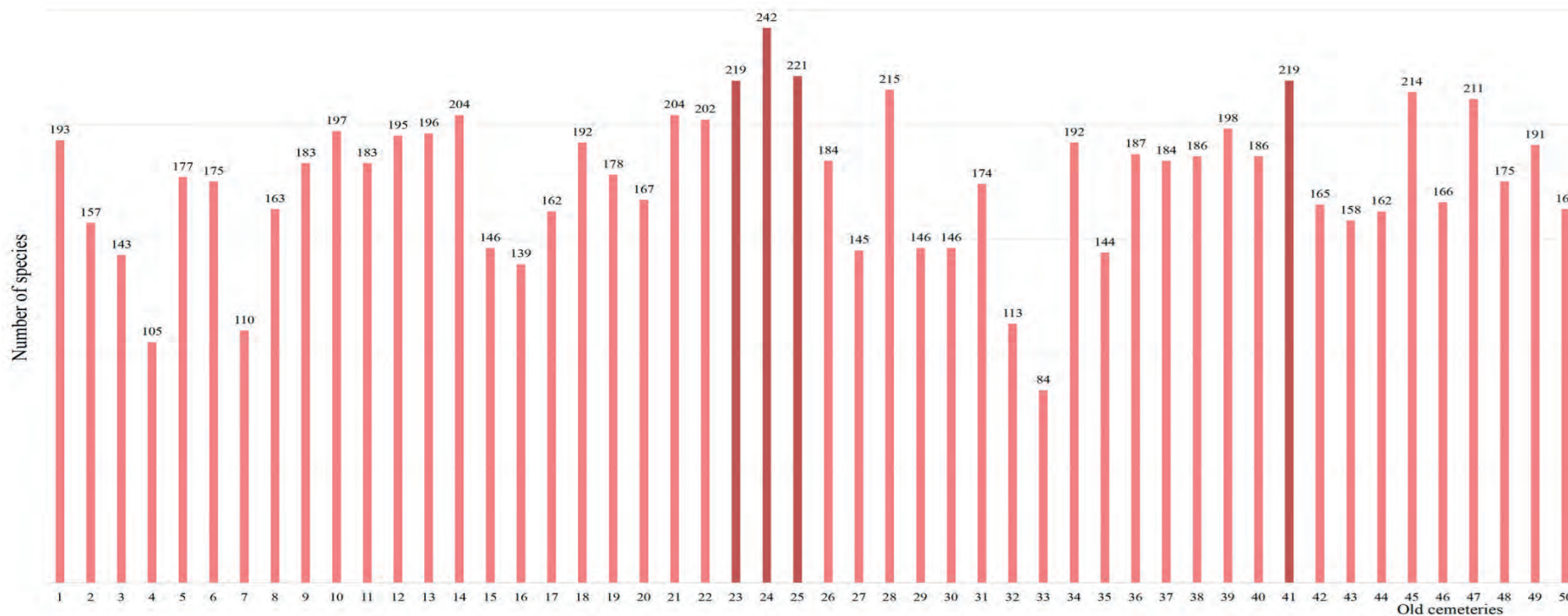


Figure 3. The total number of species in the flora of each of old cemeteries of the Right-Bank of Dnipro Grass Steppe District. Dark red color represents the three highest values. Abbreviations: 1 - Balovne, 2 - Borysivka, 3 - Buldynka, 4 - Cemetery near Kurgan Balakshova, 5 - Cemetery Zabalkivske, 6 - Chervonyi Tik, 7 - Ekonomii Ivanivka, 8 - Fedorivka, 9 - Hlyboke, 10 - Inhulka, 11 - Jewish cemetery c. Bilhorod-Dnistrovskyi, 12 - Jewish cemetery c. Kherson, 13 - Kamianka, 14 - Kherson Memorial Cemetery, 15 - Khrystoforivka, 16 - Korolivske, 17 - Kosivka, 18 - Kostiantynivka, 19 - Kozatske, 20 - Kryzhanivka, 21 - Liubopil, 22 - Lyman, 23 - Mykolaivskyi Nekropol, 24 - Nerubaiske, 25 - Nova Dofynivka, 26 - Novobohdanivka (big cemetery), 27 - Novobohdanivka (small cemetery), 28 - Odradove, 29 - Poniativka, 30 - Popazdra, 31 - Posad-Pokrovske, 32 - Prylymanske, 33 - Pshonianove, 34 - Sebyne, 35 - Shestirnia, 36 - Shyroke, 37 - Skobelev, 38 - Stanislav, 39 - Starokozachie, 40 - Sychavka, 41 - Tiahynka, 42 - Tokarivka, 43 - Trapivka, 44 - Tryfonivka, 45 - Usatove, 46 - Ust-Kamianka, 47 - Velyka Korenykha, 48 - Velyki Dalnyk, 49 - Vypasne, 50 - Yelysavetivka.

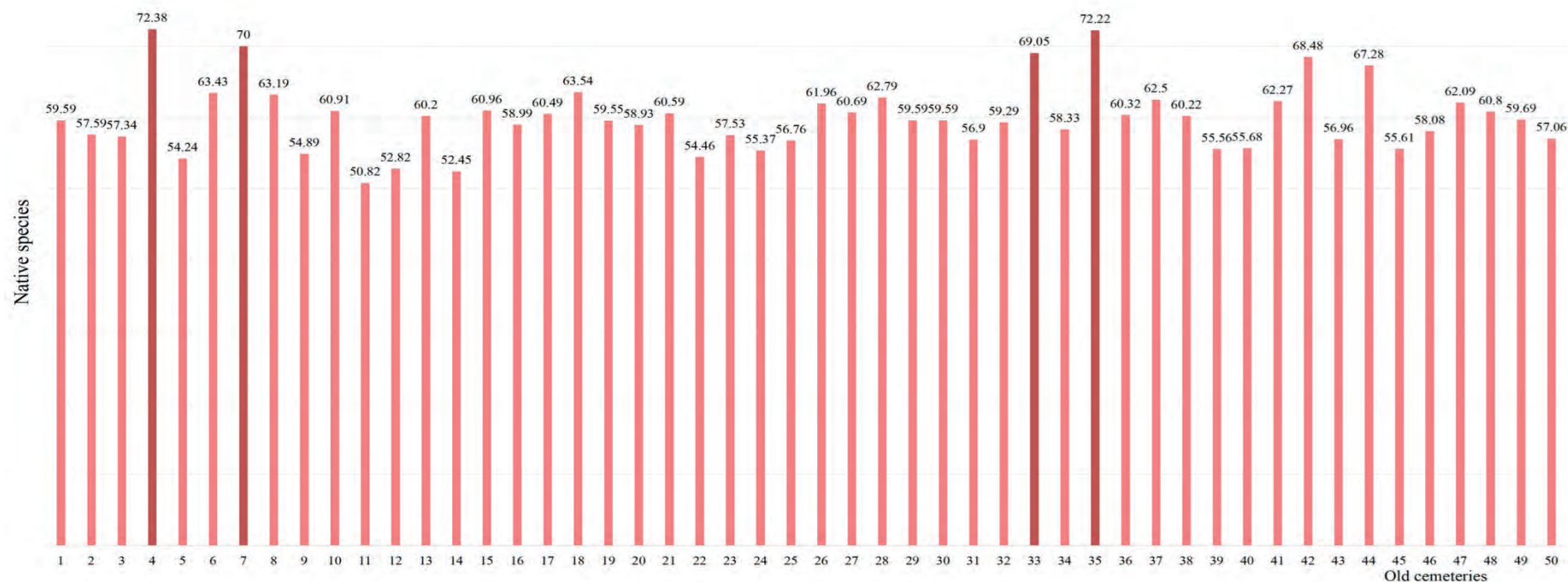


Figure 4. The shares of native species in the floristic composition for each old cemeteries. Dark red color represents the three highest values. Abbreviations: 1 -- Balovne, 2 - Borysivka, 3 - Buldynka, 4 - Cemetery near Kurgan Balakshova, 5 - Cemetery Zabalkivske, 6 - Chervonyi Tik, 7 - Ekonomiiia Ivanivka, 8 - Fedorivka, 9 - Hlyboke, 10 - Inhulka, 11 - Jewish cemetery c. Bilhorod-Dnistrovskiyi, 12 - Jewish cemetery c. Kherson, 13 - Kamianka, 14 - Kherson Memorial Cemetery, 15 - Khrystoforivka, 16 - Korolivske, 17 - Kosivka, 18 - Kostiantynivka, 19 - Kozatske, 20 - Kryzhanivka, 21 - Liubopil, 22 - Lyman, 23 - Mykolaivskiyi Nekropol, 24 - Nerubaiske, 25 - Nova Dofynivka, 26 - Novobohdanivka (big cemetery), 27 - Novobohdanivka (small cemetery), 28 - Odradove, 29 - Poniativka, 30 - Popazdra, 31 - Posad-Pokrovske, 32 - Prylymanske, 33 - Pshonianove, 34 - Sebyne, 35 - Shestirnia, 36 - Shyroke, 37 - Skobelev, 38 - Stanislav, 39 - Starokozachie, 40 - Sychavka, 41 - Tiahynka, 42 - Tokarivka, 43 - Trapivka, 44 - Tryfonivka, 45 - Usatove, 46 - Ust-Kamianka, 47 - Velyka Korenykha, 48 - Velykyi Dalnyk, 49 - Vypasne, 50 - Yelysavetivka.

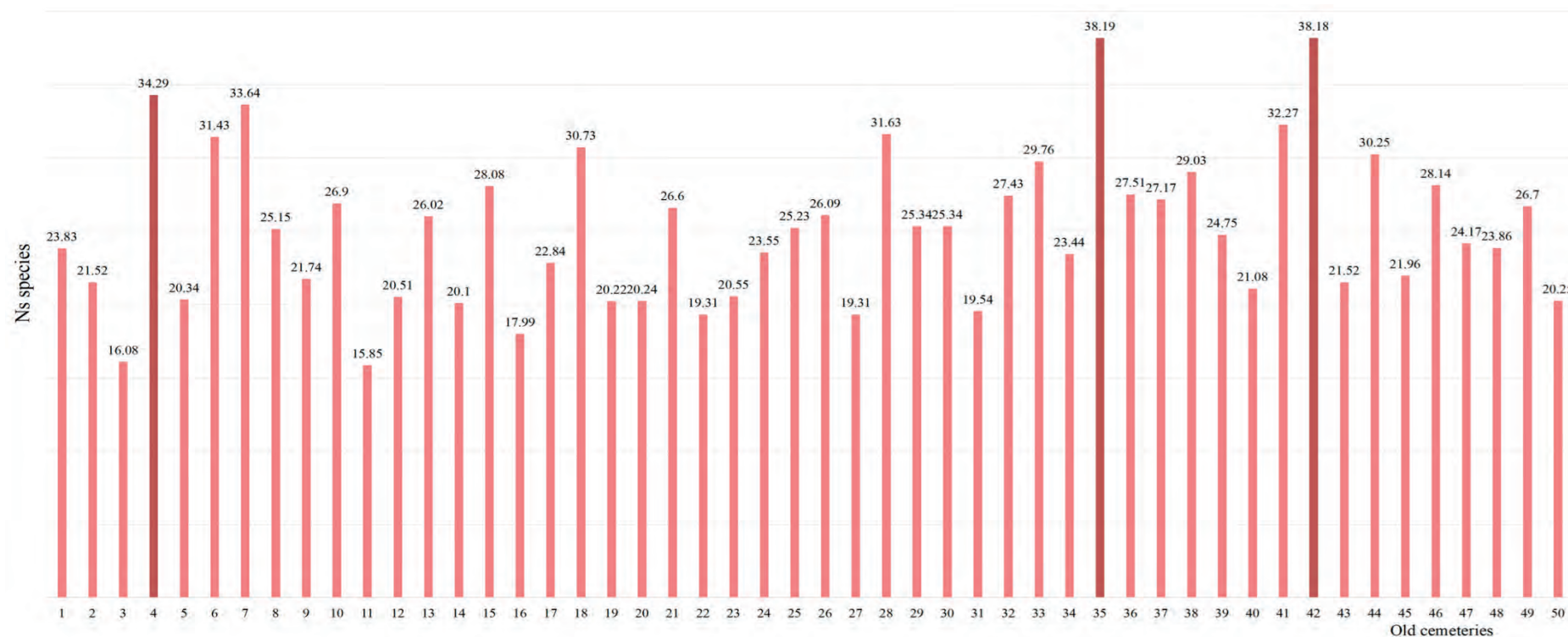


Figure 5. The shares of non-synantropic species in the floristic composition for each old cemeteries. Dark red color represents the three highest values. Abbreviations: 1 - Balovne, 2 - Borysivka, 3 - Buldynka, 4 - Cemetery near Kurgan Balakshova, 5 - Cemetery Zabalkivske, 6 - Chervonyi Tik, 7 - Ekonomii Ivanivka, 8 - Fedorivka, 9 - Hlyboke, 10 - Inhulka, 11 - Jewish cemetery c. Bilhorod-Dnistrovskiy, 12 - Jewish cemetery c. Kherson, 13 - Kamianka, 14 - Kherson Memorial Cemetery, 15 - Khrystoforivka, 16 - Korolivske, 17 - Kosivka, 18 - Kostiantynivka, 19 - Kozatske, 20 - Kryzhanivka, 21 - Liubopil, 22 - Lyman, 23 - Mykolaivskiy Nekropol, 24 - Nerubaiske, 25 - Nova Dofynivka, 26 - Novobohdanivka (big cemetery), 27 - Novobohdanivka (small cemetery), 28 - Odradove, 29 - Poniativka, 30 - Popazdra, 31 - Posad-Pokrovske, 32 - Prylymanske, 33 - Pshonianove, 34 - Sebyne, 35 - Shestirnia, 36 - Shyroke, 37 - Skobeleve, 38 - Stanislav, 39 - Starokozachie, 40 - Sychavka, 41 - Tiahynka, 42 - Tokarivka, 43 - Trapivka, 44 - Tryfonivka, 45 - Usatove, 46 - Ust-Kamianka, 47 - Velyka Korenykha, 48 - Velyki Dalnyk, 49 - Vypasne, 50 - Yelysavetivka.

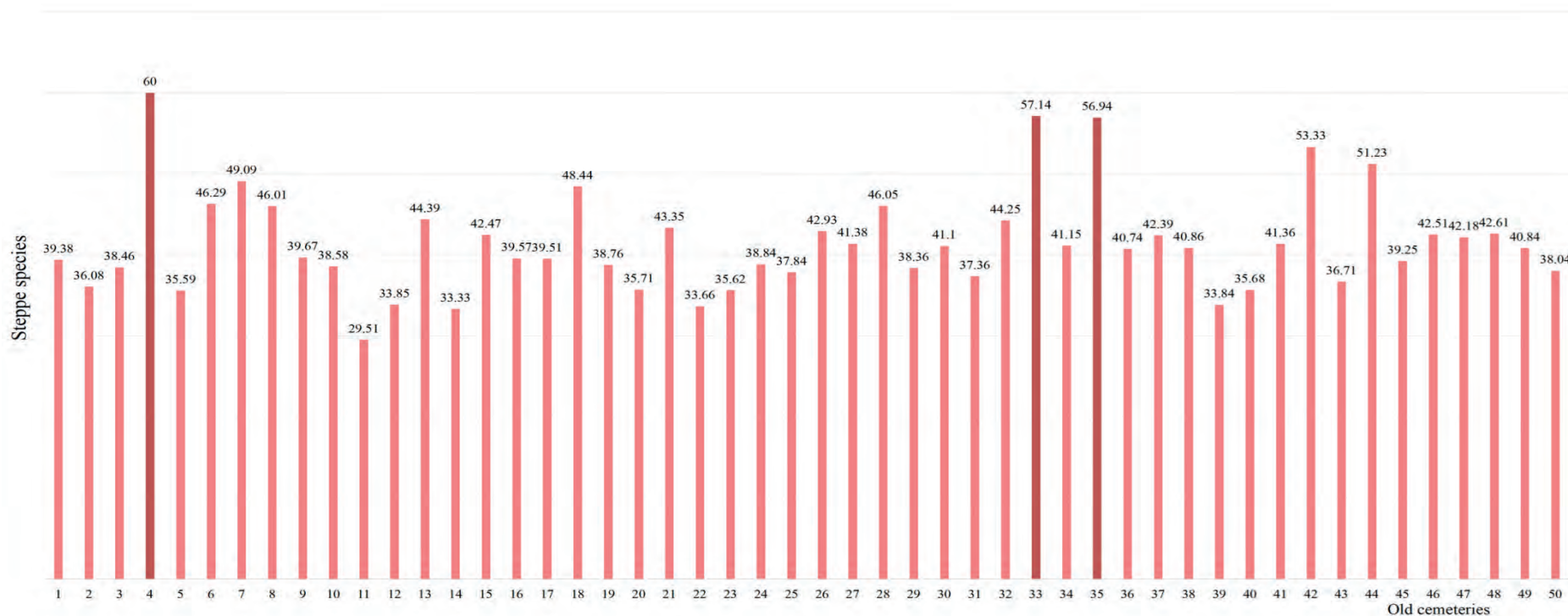


Figure 6. The shares of steppe species in the floristic composition for each old cemeteries. Dark red color represents the three highest value. Abbreviations: 1 - Balovne, 2 - Borysivka, 3 - Buldynka, 4 - Cemetery near Kurgan Balakshova, 5 - Cemetery Zabalkivske, 6 - Chervonyi Tik, 7 - Ekonomiia Ivanivka, 8 - Fedorivka, 9 - Hlyboke, 10 - Inhulka, 11 - Jewish cemetery c. Bilhorod-Dnistrovskiyi, 12 - Jewish cemetery c. Kherson, 13 - Kamianka, 14 - Kherson Memorial Cemetery, 15 - Khrystoforivka, 16 - Korolivske, 17 - Kosivka, 18 - Kostiantynivka, 19 - Kozatske, 20 - Kryzhanivka, 21 - Liubopil, 22 - Lyman, 23 - Mykolaivskiyi Nekropol, 24 - Nerubaiske, 25 - Nova Dofynivka, 26 - Novobohdanivka (big cemetery), 27 - Novobohdanivka (small cemetery), 28 - Odradove, 29 - Poniativka, 30 - Popazdra, 31 - Posad-Pokrovske, 32 - Prylymanske, 33 - Pshonianove, 34 - Sebyne, 35 - Shestirnia, 36 - Shyroke, 37 - Skobeleva, 38 - Stanislav, 39 - Starokozachie, 40 - Sychavka, 41 - Tiahynka, 42 - Tokarivka, 43 - Trapivka, 44 - Tryfonivka, 45 - Usatove, 46 - Ust-Kamianka, 47 - Velyka Korenykha, 48 - Velykyi Dalnyk, 49 - Vypasne, 50 - Yelysavetivka.

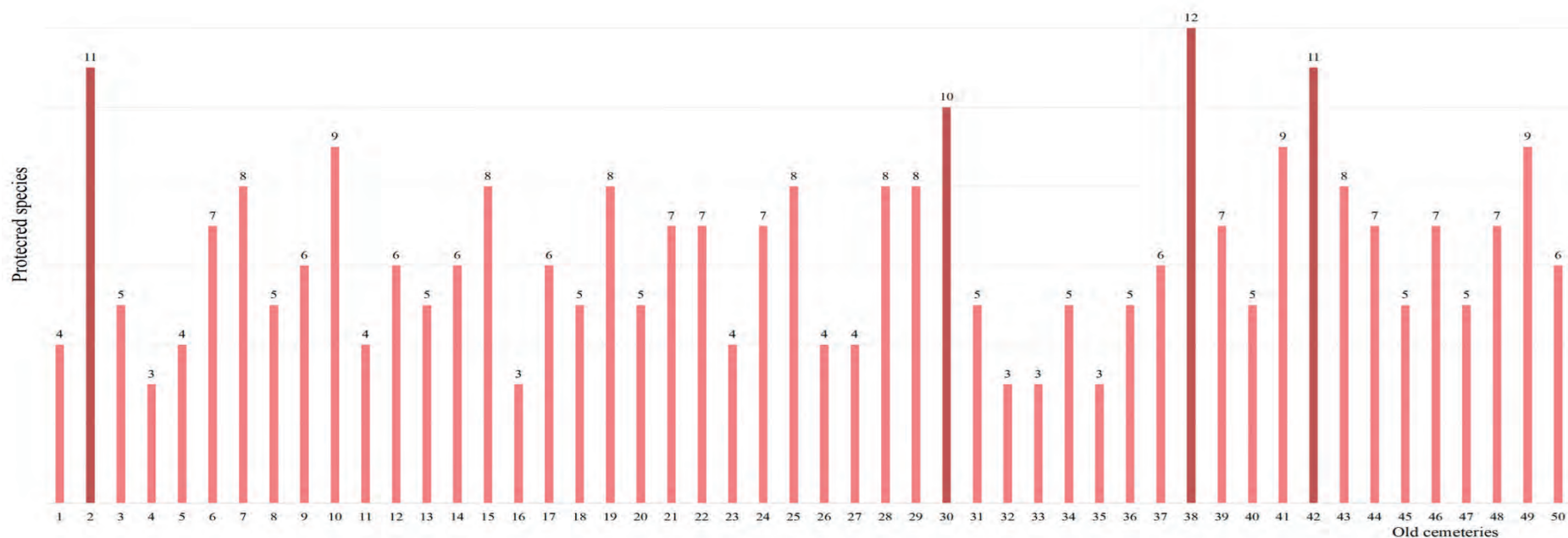


Figure 7. The total number of protected species in the floristic composition for each old cemeteries. Dark red color represents the three highest values. Abbreviations: 1 - Balovne, 2 - Borysivka, 3 - Buldynka, 4 - Cemetery near Kurgan Balakshova, 5 - Cemetery Zabalkivske, 6 - Chervonyi Tik, 7 - Ekonomii Ivanivka, 8 - Fedorivka, 9 - Hlyboke, 10 - Inhulka, 11 - Jewish cemetery c. Bilhorod-Dnistrovskiy, 12 - Jewish cemetery c. Kherson, 13 - Kamianka, 14 - Kherson Memorial Cemetery, 15 - Khrystoforivka, 16 - Korolivske, 17 - Kosivka, 18 - Kostiantynivka, 19 - Kozatske, 20 - Kryzhanivka, 21 - Liubopil, 22 - Lyman, 23 - Mykolaivskiy Nekropol, 24 - Nerubaiske, 25 - Nova Dofynivka, 26 - Novobohdanivka (big cemetery), 27 - Novobohdanivka (small cemetery), 28 - Odradove, 29 - Poniativka, 30 - Popazdra, 31 - Posad-Pokrovske, 32 - Prylymanske, 33 - Pshonianove, 34 - Sebyne, 35 - Shestirnia, 36 - Shyroke, 37 - Skobeleve, 38 - Stanislav, 39 - Starokozachie, 40 - Sychavka, 41 - Tiahynka, 42 - Tokarivka, 43 - Trapivka, 44 - Tryfonivka, 45 - Usatove, 46 - Ust-Kamianka, 47 - Velyka Korenykha, 48 - Velykyi Dalnyk, 49 - Vypasne, 50 - Yelysavetivka.

PROTECTED SPECIES OF VASCULAR PLANTS

We recorded many protected vascular plant species, according to the Resolution 6 of the Bern Convention (Revised .. 1998), the Red Data Book of Ukraine (Didukh 2009) and Regional red lists regions (Red list of Dnipropetrovsk Region, 2011; Red list of Kherson Region, 2013; Red list of Mykolaiv Region, 2012; Red list of Odesa Region, 2011).

We registered 65 protected species have a conservation status, including:

- 3 species listed in the Resolution 6 of the Bern Convention (Revised .. 1998) - *Iris hungarica*, *Jurinea cyanooides*, *Paeonia tenuifolia*.

- 16 species listed in the Red Data Book of Ukraine (Didukh 2009): *Adonis vernalis*, *A. wolgensis*, *Astragalus borysthenticus*, *A. dasyanthus*, *A. henningii*, *Betula borysthentica*, *Cymbopachma borysthentica*, *Iris hungarica*, *Ornithogalum boucheanum*, *O. refractum*, *Paeonia tenuifolia*, *Stipa capillata*, *S. lessingiana*, *S. ucrainica*, *Tulipa schrenkii*, *T. biebersteiniana*.

- 23 species included in the Regional Red List of Dnipropetrovsk Region (Red list of Dnipropetrovsk Region 2011) - *Alcea pallida*, *Allium paniculatum*, *A. rotundum*, *Anemone sylvestris*, *Astragalus corniculatus*, *Convallaria majalis*, *Convolvulus lineatus*, *Dianthus guttatus*, *Ephedra distachya*, *Goniolimon besserianum*, *Haplophyllum suaveolens*, *Hesperis tristis*, *Inula oculus-christi*, *Iris pumila*, *Kohlrauschia prolifera*, *Linaria biebersteinii*, *Padus avium*, *Salvia austriaca* (*S. revelata*), *Sedum sexangulare*, *Sempervivum ruthenicum*, *Senecio borysthenticus*, *Thymus x dimorphus*, *Valeriana officinalis*.

- 17 species included in the Regional Red List of Kherson Region (Red list of Kherson Region, 2013) - *Amygdalus nana*, *Bellevallia sarmatica*, *Centaurea trichocephala*, *Convallaria majalis*, *Dianthus andrzejowskianus*, *Elytrigia pseudo-caesia*, *Ephedra distachya*, *Fraxinus excelsior*, *Iris halophila*, *Limonium platyphyllum*, *Linaria macroura*, *Muscari neglectum*, *Peucedanum ruthenicum*, *Prangos odontalgica*, *Quercus robur*, *Veronica capsellcarpa*, *Vinca herbacea*.

- 9 species included in the Regional Red List of Mykolaiv Region (Red list of Mykolaiv Region, 2012) - *Amygdalus nana*, *Anemone sylvestris*, *Astragalus pallescens*, *Convallaria majalis*,

Ephedra distachya, *Iris pumila*, *Limonium platyphyllum*, *Polygonatum multiflorum*, *Sempervivum ruthenicum*.

- 17 species included in the Regional Red List of Odesa Region (Red list of Odesa Region, 2011) - *Achillea nobilis*, *Allium guttatum*, *Amygdalus nana* (*Prunus tenella* var. *tenella*), *Anemone sylvestris*, *Arenaria leptoclados*, *Bellevallia sarmatica*, *Convallaria majalis*, *Dianthus lanceolatus*, *Helichrysum arenarium*, *Hyacinthella leucophaea*, *Iris halophila*, *Iris pumila*, *Kohlrauschia prolifera*, *Muscari neglectum*, *Ornithogalum kochii*, *Phlomis hybrida*, *Valeriana officinalis*.

Old cemeteries face challenges in preserving biodiversity due to land elimination, repurposing, reburials, and lack of a management plan (Skobel et al., 2025). The presence of species from the Red Book of Ukraine and Regional Red Lists supports the establishment of nature conservation areas (Verkhovna Rada Ukrainy, 1992). In our opinion, old abandoned cemeteries could be declared as natural monuments. Declaration of natural monuments is carried out without expropriating land plots and other natural objects from their owners. Natural monuments are individual unique natural formations with special environmental, scientific, aesthetic, educational, and cultural significance, aiming to preserve them in their natural state (Verkhovna Rada Ukrainy, 1992).

Moreover, the presence of species listed in Resolution 6 of the Bern Convention provides a rationale for establishing an Emerald Network site in old cemeteries - for protecting sections of old cemeteries from new burials, reburials and for implementing a management plan at old cemeteries (Skobel et al., 2025). We propose to preserve the steppe flora of old cemeteries by means of orderly management. In particular mowing and cutting of tree and shrub vegetation (Skobel et al., 2025). Since preservation and spirituality are closely intertwined in, it is believed that the restoration of deteriorated sacred and spiritual traditions of local communities contributes to the preservation of natural flora (Löki et al., 2019a,b). It is pertinent to highlight that there is a movement in Ukraine aimed at preserving the cemeteries of the

NGO Ukraine Incognita within the framework of the “Ancient Cemeteries of Ukraine” project (Ukraine Incognita, 2024). The long-term preservation of the biodiversity of old cemeteries can be achieved by implementing comprehensive

protection measures, including designation as an object of cultural heritage and from the perspective of biodiversity conservation (Skobel et al., 2025).



Figure 8. Protected species of the old cemeteries Right-Bank of Dnipro Grass Steppe District. Photos: A - *Amygdalus nana*; B - *Bellevalia sarmatica*; C - *Stipa capillata*; D - *Vinca herbacea*. Photos by N. Skobel

Conclusions

Our study confirmed that old cemeteries preserve valuable remnants of steppe habitats and have the potential of being local hotspots of plant diversity. Despite their relatively small size, they appeared to be enormously species-rich enclaves of steppe flora.

Old cemeteries located in rural villages often serve as unique ecological niches that exhibit a remarkable resilience against the pressures typically faced by more urbanized areas. These sites generally experience lower levels of human disturbance.

Several factors contribute to this

phenomenon. First and foremost, the absence of significant human pressure—such as the introduction of alien species. In urban environments, invasive plants often outcompete local species, disrupting the ecological balance. However, in rural cemeteries, the lack of such invasive pressures enables the preservation of indigenous steppe plants, which have adapted to the specific conditions of the local environment.

Additionally, cultural practices associated with grave maintenance, such as planting flowers or the ploughing of graves, tend to be less intensive in rural cemeteries compared to their urban counterparts. In cities, regular upkeep

can lead to soil disturbance and the introduction of non-native species, which can further threaten local biodiversity.

At present Ukrainian non-numerous old cemeteries are preserved as archaeological monuments, but the natural value of these sites is not taken into account by law. Old cemeteries in Ukraine face significant challenges in preserving biodiversity due to land repurposing, reburials, and the absence of management plans. These sites often host protected species and could be designated as natural monuments or part of the Emerald Network to safeguard their ecological and cultural value. The lack of management plans leads to neglect, high number of alien plants and shrubs on old cemeteries, which can be mitigated through controlled by management plan: mowing and the prevention of harmful practices such as littering and vandalism. The long-term preservation of biodiversity in old cemeteries can be achieved through comprehensive protection measures,

such as designating them as cultural heritage sites and implementing biodiversity conservation strategies and informational campaign on more 'nature-friendly' burial care on old cemeteries in southern Ukraine.

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ZNO NANOPARTICLES IMPACT THE PHOTOSYNTHETIC AND ENZYME ACTIVITY OF BARLEY (*HORDEUM VULGARE*) PLANTS IN DROUGHT CONDITIONS

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Abstract: *The use of nanomaterials, especially nanoparticles, in plant physiology is crucial for understanding their effects on plant development and productivity, as well as for assessing potential environmental risks to food safety and human health. Zinc oxide nanoparticles are among the most widely produced, used, and likely to be released into the environment. The study assessed the effects of ZnO nanoparticles on the photosynthetic activity, pigment content, enzymes activity of barley (*Hordeum vulgare*) plants under normal irrigation and drought conditions. The results showed that the application of ZnO nanoparticles improved the resistance of barley plants to drought stress. This was evidenced by increased chlorophyll pigment and carotenoids levels in the leaves, decreased activity of antioxidant enzymes (CAT, POX and APX) under drought stress, and significant change in the Fv/Fm parameter of chlorophyll fluorescence (ChlaF). In conclusion, our findings suggest that ZnO nanoparticles played a significant role in enhancing the tolerance of plants to drought stress.*

Keywords: *nanoparticles, barley plants, zinc oxide, drought, photosynthetic activity, pigments, enzymes*

Introduction

To combat drought, plants undergo morphological changes in their aboveground organs and roots, synthesize reactive oxygen species, and stress hormones such as ethylene and abscisic acid. They also close stomata in leaves, and reduce the synthesis of chlorophyll and other pigments through various mechanisms (Etesami et al., 2015; Chiappero et al., 2019; Bhat et al., 2021). Depending on the duration of drought stress, plant responses can be short-term or long-term. Short-term responses may include reduced carbon assimilation, impaired osmotic regulation and growth, hydraulic changes, and the generation of signals indicating cell desiccation. If normal conditions are quickly restored, these reactions do not have serious conse-

quences for plants. However, during long-term stress, irreversible changes occur in plants ultimately leading to their death (Kaur and Asthir, 2017).

Recent studies have shown that the use of ZnO nanoparticles as fertilizers is effective in playing an important role in plant growth and development, ultimately increasing yield. Plants can be fed more gradually with ZnO nanoparticles compared to conventional fertilizers (Rossi et al., 2019; Ajey Singh et al., 2018). The role of nanoparticles (e.g. TiO₂, ZnO, Fe₂O₃, Fe₃O₄, CuO, Mn) in enhancing plant drought tolerance has been intensively studied recently. The results of these studies have shown that TiO₂ nanoparticles, due to their characteristic photocatalytic properties, stimulate the photosyn-

thesis process in plants, enhance the light absorption capacity of chloroplasts, regulate light distribution between PSI and PSII, increase the energy yield of photosynthesis, and intensify the photolysis process of water (Ze et al., 2013).

Zinc is one of the most important micro-nutrients for plants as it is involved in catalyzing many metabolic reactions as a component of various enzymes. Zinc plays a crucial role in plant disease resistance, photosynthesis efficiency, chlorophyll content improvement, protein synthesis, structuring biological membranes, pollen formation and increasing the activity of antioxidant enzymes in plant tissues (Azhar Hussain et al., 2015). Without zinc, plant growth slows down, photosynthesis intensity decreases, organic substances synthesis is limited, plant resistance to diseases and stress weakens, and productivity decreases. Zinc is a component of enzymes involved in photosynthesis, such as ribulose 1, 5-biphosphate carboxylase (RuBPC), catalyzing the initial stage of carbon dioxide fixation in plants like beans, barley, and rice (Komal Rudani et al., 2018). Zinc is also integral to biological molecules, like lipids, proteins, and auxins, playing as a co-factor in plant nucleic acid metabolism (Mengel et al., 2001). High doses of zinc can be to plants, inhibiting cell growth and division in tissues (Tsonev et al., 2012).

Studies have shown that zinc can enhance drought tolerance in plants like wheat, sunflower, tomato, and red cabbage (Hajiboland et al., 2010; Sadoogh et al., 2014; Eslami et al., 2014). Recently there has been a growing inter-

est in producing nano forms zinc and applying them in agriculture particularly in enhancing plant drought resistance. One promising approach to mitigating drought effects in plants is the use of nanoparticles. Experiments have demonstrated that applying ZnO nanoparticles to wheat plant leaves can mitigate the negative effects of drought stress and improve yield components (Taran et al., 2017). Recent studies have also shown that using ZnO nanoparticles as fertilizers can effectively promote plant growth and development, ultimately increasing yield. Plants can absorb nutrients more efficiently from ZnO nanoparticles compared to conventional fertilizers (Rossi et al., 2019). This research study focuses on the positive effects of ZnO nanoparticles on barley plants grown under normal irrigation and drought stress conditions. It explores changes in plant photosynthetic activity, improvements in pigment composition, and effects on the activity of antioxidant enzymes.

2. Materials and methods

2.1 Experimental object. The experiments utilized the winter barley variety "Qarabagh 22" developed at the Agricultural Research Institute. This variety has a vegetation period of 193-210 days, a stem height of 65-75 cm, a scaly spike shape, and medium length and density. It can yield 7.0-7.5 tons, with medium-sized grains (42 g) and a high germination rate (95%). Additionally, this variety shows resistance to salt and drought.



Figure 1. Barley (*Hordeum vulgare*): A-seeds, B-Spike, C-barley field

2.2. Experimental design. Barley plant experiments were conducted in laboratory conditions, using a Plant Growth Chamber miniphytotron. Healthy, undamaged barley seeds were first selected, sterilized in an H_2O_2 solution and then dried. After drying, the seeds were either coated with ZnO nanoparticles powder in a VORTEX apparatus before sowing in one variant, or soaked in a 1mg/l solution of ZnO nanoparticles for 24 hours in the second variant. The barley seeds were then sown in 6 vegetation pots each filled with 2 kg of soil. 30 seeds were planted in each pot. The soil used for barley cultivation was sourced from the Chukhuryurd area of the

Shamakhi region in Azerbaijan. Prior to use, the soil was air-dried, cleaned of residues, crushed and sieved for physical and chemical analyses (<2 mm). The pH of the soil was determined using a potentiometric method with glass electrodes in a 1:2.5 soil-solution ratio of deionized water and 1 M KCl solution. The $CaCO_3$ content was measured using a calcimeter after dissolving the carbonates in the soil with 10% HCl. The particle size distribution of the soil was determined using the pipette method (Fiala et al., 1999).

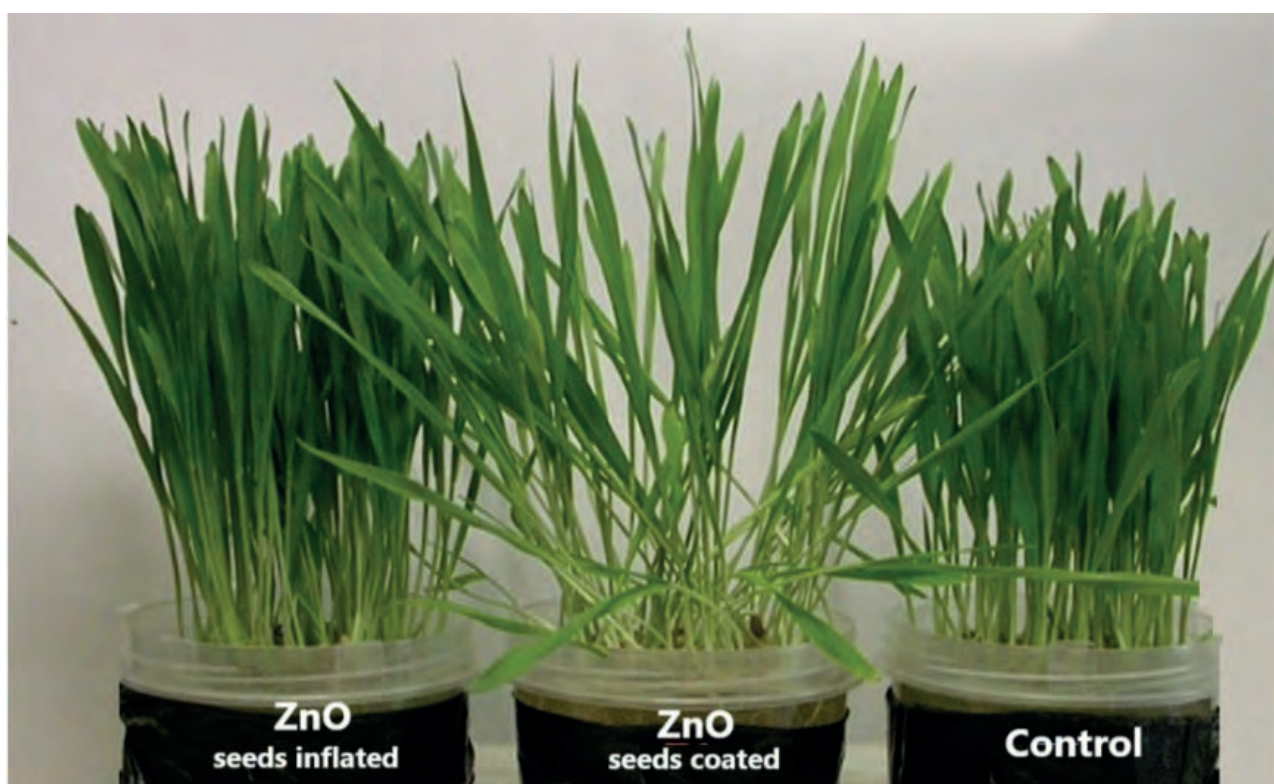


Figure 2. Effect of ZnO nanoparticles on barley seedlings under normal irrigation conditions

2.3. XRD and FTIR Characterization of ZnO nanoparticles. ZnO nanoparticle (99.8%, 10-30 nm) s are produced by the US company SkySpring Nanomaterials, Inc. They are semiconductors with a bandgap of 3.37 eV at room temperature. ZnO nanoparticles possess good antibacterial, and anti-corrosion properties, are effective against fungi, and are utilized in UV radiation filtration. They are incorporated into ointments and creams for treating of skin diseases, in rubber manufacturing, in cigarette filters, as additives in concrete products, in the ceramic industry, as a coating agent in paint products, and as additives in food production (Shah Faisal et al., 2022). X-ray diffraction (XRD) analysis confirms the absence of crystals of any other substance in ZnO nanoparticles. The FTIR spectrum of ZnO nanoparticles reveals a wavenumber of 3447 cm^{-1} corresponding to the O-H group, and 1620 cm^{-1} associated with the Zn-O vibration.

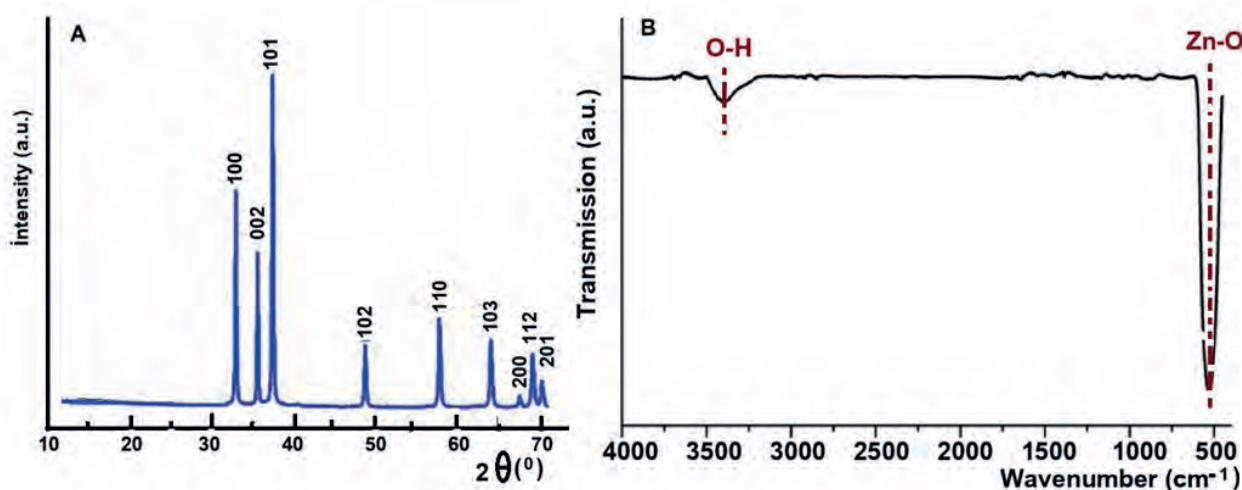


Figure 3. XRD pattern (A) and FTIR spectrum (B) of ZnO nanoparticles.

2.4 Measurements of chlorophyll fluorescence

Chlorophyll fluorescence measurements were conducted on barley leaves that were dark-adapted for 30 minutes. The leaves were dark-adapted to ensure that the photosynthetic reaction centers were relaxed and in an open state. A Chla fluorescence image was captured on the adaxial side of the leaf using a spectrophotometer (Cary Eclipse, Varian and Austrian). The device utilizes a xenon lamp as a source of illumination. The fluorometer is capable of recording light rays emitted by the samples in 4 modes. It's high scanning speed (24,000 nm/inch) allows for acquisition of a full spectrum in just 3 minutes. Excitation and emission spectra range from 200-900 nm for leaves.

2.5 Pigment contents. The total contents of chlorophylls a, b, and carotenoids were measured following to the procedure outlined by Linchenthaler and Wellburn (1983). Briefly, fresh samples weighing 0.1 g were homogenized in 95% acetone (Merck, Germany) and the absorbance was measured spectrophotometrically at 440, 645, and 663 nm. The results were then calculated using the following equations:

$$\text{Chl a (mg/g)} = 9,784 \times A_{663} - 0,990 \times A_{645}$$

$$\text{Chl b (mg/g)} = 21,426 \times A_{645} - 4,650 \times A_{663}$$

$$\text{Chl (a + b) (mg/g)} = 5,134 \times A_{663} + 20,436 \times A_{645}$$

$$\text{Carotenoids (mg/g)} = 4,695 \times A_{440} - 0,268 \times (\text{a} + \text{b})$$

After calculating the concentrations, the amount of pigment per gram of fresh material was determined using the following formula:

$$C = c_1 V r / m$$

Here, **C** represents the amount of pigment in the wet weight of the sample (mg/g); c_1 is the pigment concentration calculated by the given formula (mg/l); **V** is the initial volume of the extract (ml); **r** is the dilution factor; and **m** is the weight of the sample (g). Based on the quantities used in the experiment, $m = 0.1$ g, $r = 1$, and $V = 10$ ml were calculated.

2.6 Determination of catalase enzyme (CAT) activity

The method proposed by Narwal et al. (2009) was utilized to determine catalase (CAT) activity. According to this method, activity was assessed by measuring the reduction in absorbance at a wavelength of 240 nm following the breakdown of hydrogen peroxide (H_2O_2). The reaction mixture comprised 50 μL of supernatant, 1.95 ml of 0.1 M potassium phosphate buffer (pH 7.0) and 100 μL of 264 mM H_2O_2 . Absorbance reduction was recorded at 5-second intervals for 100 seconds at room temperature (25°C). One unit of CAT activity corresponds to 1 mMol of H_2O_2 consumed per mg of protein per minute using an extinction coefficient of 40 $\text{mM}^{-1} \text{cm}^{-1}$ (Narwal et al., 2009).

2.7 Determination of guaiacol peroxidase (POX) enzyme activity

The method for measuring guaiacol peroxidase (POX) enzyme activity was first described by MacAdam et al. (1992). In summary, 50 μL of plant extract was combined with 1.35 ml of 0.1 M potassium phosphate buffer (pH 6.0), 100 μL of 45 mM guaiacol, and 500 μL of 44 mM hydrogen peroxide. The changes

in absorbance at 470 nm were then monitored kinetically using a UV-Vis spectrophotometer at 25 °C for 300 s with 10 s intervals. One unit of POX activity is equivalent to 1 mmol of tetraguaiacol consumed per mg of protein per minute with an extinction coefficient of 26.6 mM⁻¹ cm⁻¹ (MacAdam et al., 1992).

2.8 Determination of ascorbate peroxidase (APX) enzyme activity. APX activity was determined using the method proposed by Narwal et al. (2009). This method, measures APX activity by monitoring the rate of ascorbate oxidation with H₂O₂. A mixture was prepared consisting of 2.4 mL of 0.1 M potassium phosphate buffer (pH 7.0), 250 µL of 1.2 mM Na₂EDTA, 50 µL of 35 mM H₂O₂, 100 µL of acid, 100 µL of MbOc and ascorbic acid. The reduction of ascorbic acid was then measured at room temperature (25°) in a spectrophotometer at a wavelength of 290 nm for 500 s with 10 s intervals. Enzyme activity was calculated using an extinction coef-

ficient of 8 mM⁻¹ cm⁻¹. One unit of APX activity is defined as 1 mMol of ascorbate oxidized per mg of protein per second.

3. Results and discussion

3.1 Effect of ZnO nanoparticles NPs effect on chlorophyll a fluorescence

In our experiments with barley leaves, we utilized Chlorophyll fluorescence (ChlaF) to investigate the impact of ZnO NPs on plant photosynthesis. ChlaF is a well-established method for assessing photosynthetic capacity and some of the parameters used to assess normal plant development or development under stressful conditions. For monitoring, the maximum efficiency operation of PSII operation is typically measured as Fv/Fm after a period of dark adaptation. This parameter offers a comprehensive understanding of plant efficiency under environmental stress conditions (Murchie et al., 2013).

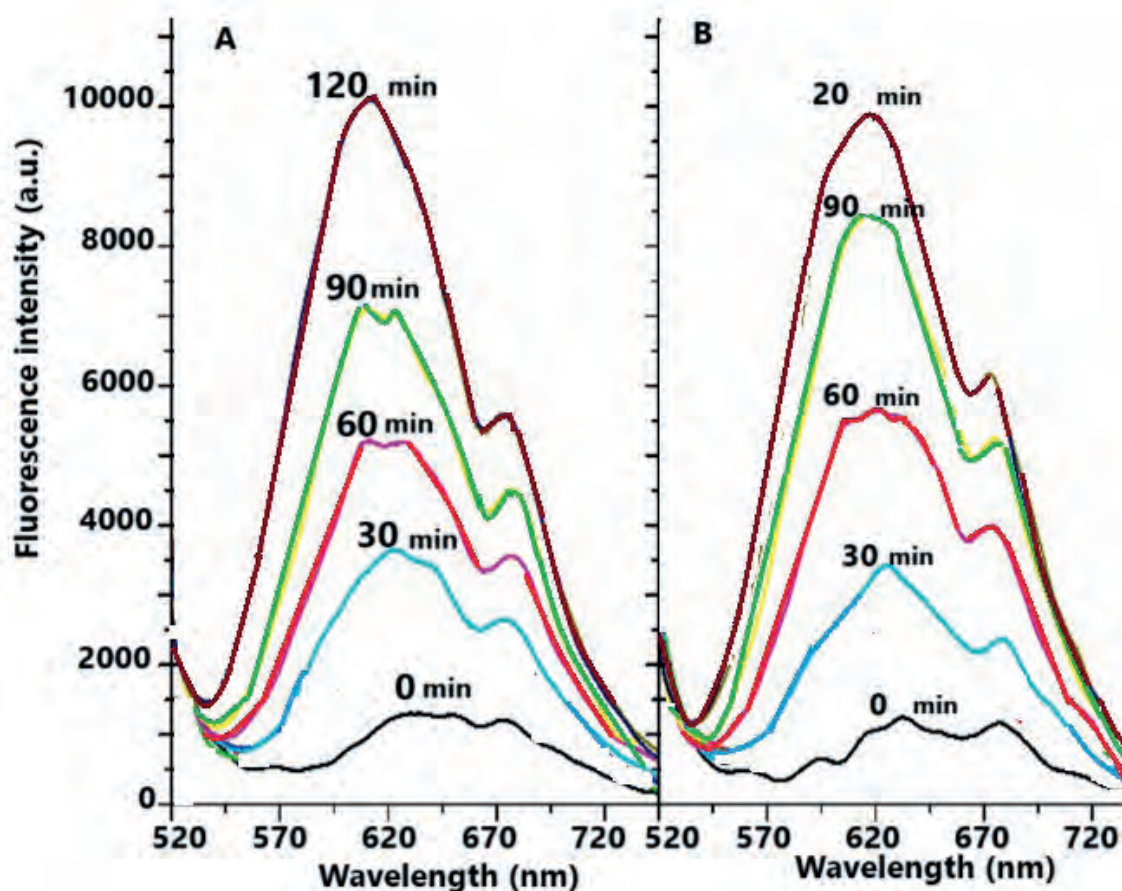


Figure 4. Fluorescence spectra of barley leaves treated with ZnO nanoparticles (A - under normal irrigation conditions, B - under drought conditions) as a function of time under blue light irradiation, associated with ROS production.

Figure 4 shows the fluorescence spectra of barley leaves under normal irrigation conditions and under drought stress. These spectra indicate that ZnO nanoparticles can quickly induce the production of reactive oxygen species (ROS) when exposed to light. The ROS produced

by ZnO nanoparticles in the 530-730 nm range is attributed to the formation of ethidium molecules. It is important to note that the value of kROS obtained is low as fluorescence does not detect all types of ROS.

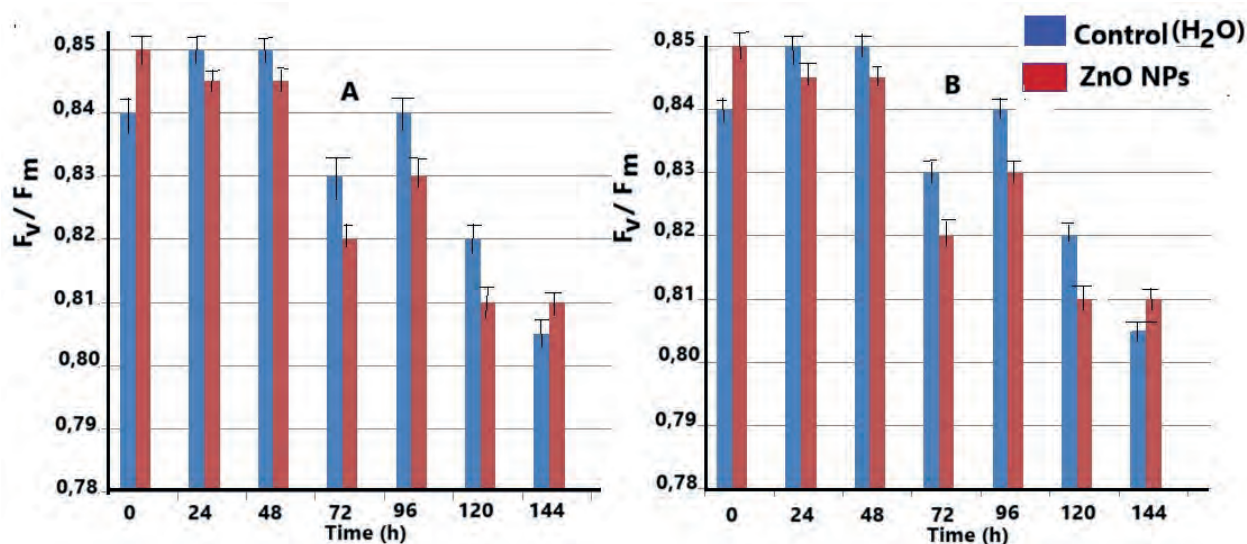


Figure 5. F_v/F_m of Barley (*Hordeum vulgare*) plants as a function of time treated with ZnO nanoparticles (A - under normal irrigation conditions, B - under drought conditions) (t -test, $p < 0.05$, $n = 6$).

A ChlaF analysis was conducted by monitoring the fluorescence parameter F_v/F_m of chlorophyll in barley (*Hordeum vulgare*) plants over time, both under normal irrigation conditions and during drought conditions, while being treated with ZnO nanoparticles. Figure 5 illustrates that ZnO nanoparticles caused insignificant changes in F_v/F_m under normal irrigation conditions, but noticeable changes were observed under drought conditions. The nanoparticles led to a systemic decrease in F_v/F_m for both control and treated plants depending on the time after internalization in leaves. Therefore, in addition to the systematic effect observed in both solutions (control and exposed to ZnO nanoparticles), nanoparticles could also have an additional localized effect on the F_v/F_m of leaves treated with nanoparticles.

3.2 Effect of ZnO nanoparticles on the activity of catalase (CAT), ascorbate peroxidase (APX) and guaiacol peroxidase (POX) enzymes under drought conditions.

As described in the experimental methodol-

ogy, ZnO nanoparticles were applied to barley seeds in two different ways. In one approach, the seeds were coated with ZnO nanoparticles, while in the second approach, the seeds were soaked in colloidal solution of ZnO nanoparticles for 24 hours after being pre-soaked in an ultrasonic device for 10 minutes. Samples were collected from the seedlings at the three-leaf stage when they were 15 days old in the Plant Growth Chamber incubator. The activities of the antioxidant enzymes catalase, ascorbate peroxidase and guaiacol peroxidase were analyzed in the leaves of the plants. The results of the experiments are shown in Figure 6. It is well documented that the activity of antioxidant enzymes such as catalase, peroxidase, superoxide dismutase and polyphenol oxidase) increases in leaf extracts during drought stress (Sadat Hosseini et al., 2018; Nasirzadeh et al., 2021).

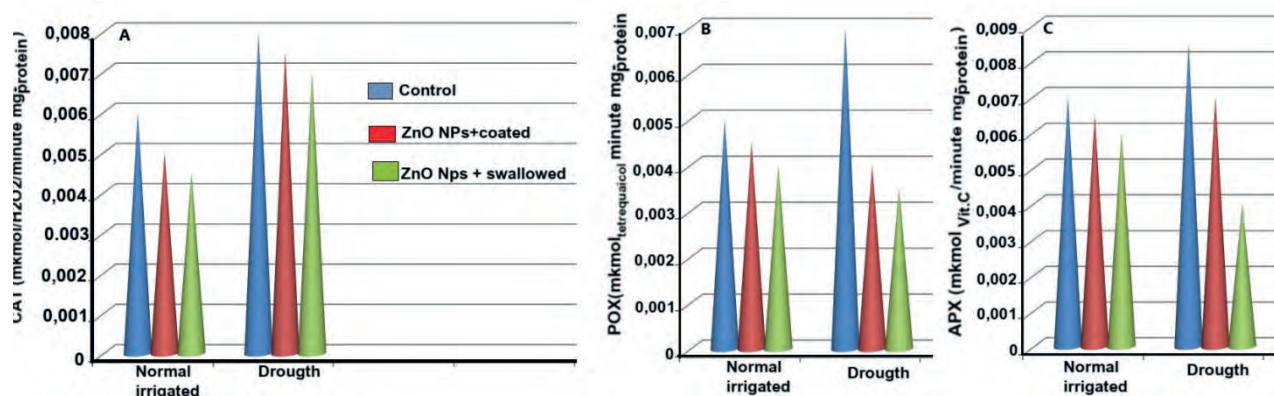


Figure 6. Changes in barley's leaf catalase (CAT) (A), guaiacol peroxidase (POX) (B) and ascorbate peroxidase (APX) (C) activities by applying ZnO nanoparticles

As mentioned in the experimental methodology, ZnO nanoparticles were applied to barley seeds in two different ways. In one method, the seeds were coated with ZnO nanoparticles, while in the second method, the seeds were soaked in colloidal solution of ZnO nanoparticles for 24 hours after being pre-soaked in an ultrasonic device for 10 minutes. Samples were collected from the seedlings at the three-leaf stage when they were 15 days old in the Plant Growth Chamber incubator. The activities of the antioxidant enzymes catalase, ascorbate peroxidase and guaiacol peroxidase were measured in the leaves of the plants and the results are presented in Figure 4.

It is known that during drought stress, the activity of antioxidant enzymes such as catalase, peroxidase, superoxide dismutase and folylphenol oxidase increases in leaf extracts (Castillo et al., 1992). Peroxidases facilitate oxidative reactions and reduce H_2O_2 . Therefore, peroxidases are oxidoreductases that utilize H_2O_2 as an electron receptor to catalyze various oxidative reactions (Vamos-Vigyazo, 1981). Under normal irrigation conditions, oxidative stress is observed in barley plants due to the presence of ZnO nanoparticles. These nanoparticles accelerate the formation of reactive oxygen species (ROS) (Dimkpa et al., 2012), leading to an increase in peroxidase enzyme activity. ZnO nanoparticles may play a crucial role in enhancing plants' tolerance to water stress by

ROS. The nanoparticles not only impact plant water availability, dry matter accumulation, and changes in antioxidant balance under water stress but also minimize the effects of stress by reducing peroxidase enzyme activity as demonstrated in this study.

3.3s Effect of ZnO nanoparticles on pigment content in barley leaves under drought conditions.

One response of plants to drought stress is a change in pigments that are essential for the photosynthesis process. Detailed studies have shown that under normal irrigation conditions, the total amount of chlorophyll pigment in plants is at its highest. However, water deficiency can reduce the amount of chlorophyll to varying degrees at different stages of plant development. For instance Yari et al. (2005) demonstrated in their experiments that water stress leads to a significant decrease in chlorophyll in plant leaves. Addressing the reduction of chlorophyll content in plant leaves during water stress is crucial for increasing their drought tolerance. Several methods have been suggested for this purpose. For example, it has been observed that the total chlorophyll content increases when zinc is used as a fertilizer under drought conditions (Zafar et al., 2014).

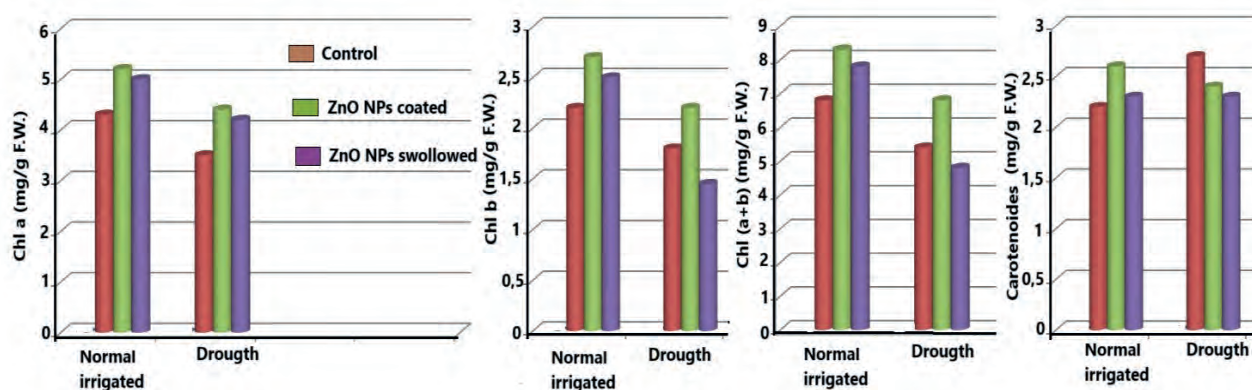


Figure 7. The content of photosynthetic pigments: chlorophyll a, chlorophyll b, total chlorophyll and carotenoids in 15 days old barley leaves. ZnO nanoparticles were applied in different conditions

The effects of zinc nanoforms, especially ZnO nanoparticles, on physiological properties in plants have yielded more interesting results. For example, the results of experiments by Ilona Plaksenkova et al. (2020) showed that the application of ZnO nanoparticles to barley (*Hordeum vulgare* L.) plants enhances seed germination, root development, and increases the level of H_2O_2 stress (Ilona Plaksenkova et al., 2020). In our experiments, we investigated the content of Chla, Chlb and carotenoids in the leaves of 15-day-old barley plants cultivated in laboratory conditions under both normal irrigation and drought stress. The application of ZnO nanoparticles was done by soaking the seeds, as mentioned in the methodology, and also by keeping them in a colloidal solution of ZnO nanoparticles for 24 hours and swelling them. The results of the experiments are presented in Figure 7. As shown in the graphs, ZnO nanoparticles increase the amount of pigments in all cases in the normal irrigation variant. Under drought stress, the amount of pigments decreased significantly as expected. However, ZnO nanoparticles eliminated this decrease and increased the amount of pigments. The effect of ZnO nanoparticles was more pronounced in the variant of cultivation after covering the seeds with these nanoparticles.

Conclusion

The results of these experiments demonstrated that ZnO nanoparticles changed the physiological status of barley (*Hordeum vulgare*) plants depending on the condition of the solution, altering the functioning of PSII. A decrease in Fv/Fm indicates a decrease in the photochemical efficiency of PSII and a change in the photosynthetic apparatus. The data also suggest that physiological changes in plants may be linked to the generation of reactive oxygen species (ROS) by the nanoparticles themselves. Additionally, the results of the experiments showed that ZnO nanoparticles can contribute to the drought resistance of barley plants. It is evident from the results that ZnO nanoparticles have a positive impact on pigment composition when applied under normal irrigation conditions. ZnO nanoparticles increase pigment levels in all cases under normal irrigation. However, under drought stress, pigment levels decreased significantly. ZnO nanoparticles may play a crucial role in enhancing plants' tolerance to water stress by repairing damage caused by ROS, affecting plant water availability, dry matter accumulation, and changes in antioxidant balance under water stress. This study demonstrates that ZnO nanoparticles minimize the effects of stress during water stress by reducing the activity of peroxidase enzymes. The effectiveness of ZnO nanoparticles is more pronounced in the cultivation variant after treating the seeds with these nanoparticles.

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ASSESSING ECOLOGICAL SUITABILITY OF *INULA GRANDIS* THROUGH CLIMATE MODELINGGulzoda Ermatova^{1*} | [ORCID:0009-0008-0242-3169](https://orcid.org/0009-0008-0242-3169)Nasibahon Naraliyeva² | [ORCID:0000-0002-6720-2083](https://orcid.org/0000-0002-6720-2083)Gulbahor Ibrohimova³ | [ORCID:0009-0001-5491-2596](https://orcid.org/0009-0001-5491-2596)Abdulla Rakhmataliev⁴ | [ORCID:0009-0009-3023-0046](https://orcid.org/0009-0009-3023-0046)Ziyoviddin Yusupov⁵ | [ORCID:0000-0003-2278-542X](https://orcid.org/0000-0003-2278-542X)¹Department of Ecology and Botany, Andijan State University, Andijan, Uzbekistan²Department of Ecology and Botany, Faculty of Natural Sciences, Andijan State University, Andijan, Uzbekistan³Department of Ecology and Botany, Faculty of Natural Sciences, Andijan State University, Andijan, Uzbekistan⁴Research Institute of the Environment and Nature Protection Technologies, Andijan, Uzbekistan⁵UAS, Institute of Botany, Molecular Phylogeny and Biography Lab, Tashkent, Uzbekistan^{1*}Correspondence: gulzoda1712@mail.ru; n_naraliyeva@mail.ru

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Abstract. This article utilizes MaxEnt modeling to determine suitable ecological habitats for *Inula grandis*, a valuable medicinal plant, aiming to support conservation planning and plantation establishment under current and future climate conditions. Species occurrence data were obtained from open-access biodiversity databases, while 19 bioclimatic variables and elevation were used as environmental predictors. The jackknife test identified four key variables influencing habitat suitability: maximum temperature of the warmest month, average temperature of the warmest quarter, precipitation of the warmest month, and precipitation of the wettest quarter. These variables highlight the species' preference for warm temperatures and adequate rainfall during growth periods. Modeling results indicate that suitable habitats are mainly located in the foothills and slopes of the Pamir-Alay and Tien Shan mountain ranges, particularly in Tashkent, Jizzakh, Samarkand, Kashkadarya, Surkhondarya, Andijan, and Fergana. The study recommends establishing managed plantations in these areas to support conservation and sustainable cultivation. Under the RCP 8.5 climate scenario for 2050, predicted shifts in habitat suitability stress the need for proactive strategies. The findings contribute essential data for biodiversity preservation, climate adaptation, and species-focused conservation planning.

Keywords: *Inula grandis*, Yellow Elecampane, species distribution range, climatic factors, MaxEnt modeling, optimal ecological habitat.

Introduction

The genus *Inula* L. belongs to the Asteraceae family, with 78 species currently identified and distributed worldwide (<https://powo.science.kew.org/>). In Uzbekistan, this genus is represented by 10 species: *Inula britannica* L., *Inula caspica* F.K. Blum. ex Ledeb., *Inula glauca* C. Winkl., *Inula helenium* L., *Inula*

macrolepis Bunge, *Inula grandis* Schrenk ex Fisch. & C.A. Mey., *Inula multicaulis* Fisch. & C.A. Mey., *Inula rhizocephala* Schrenk, *Inula rhizocephaliformis* Kamelin & Turak., and *Inula salicina* L. *Inula grandis* Schrenk ex Fisch. & C.A. Mey. is a widely distributed medicinal plant in Central Asia.

Widely recognized in folk medicine as

“Yellow Elecampane”, *Inula grandis* has been traditionally employed in the treatment of pulmonary tuberculosis (TB), various gastrointestinal conditions, and brucellosis infections. Controlled clinical trials report therapeutic efficacy of *Inula grandis* decoctions in managing peptic ulcer disease (including gastroduodenal ulcers), inflammatory conditions (gastritis, duodenitis, periduodenitis), and chronic constipation, with particularly promising results in adjunctive gastric cancer therapy showing statistically significant symptom relief (Vyhodtsev, 1958; Dusmatova, 2019; Sokolov, 1993).

The increasing demand for *I. grandis*, particularly for commercial harvesting, poses a serious threat to the survival of this species in its natural habitat. The growing demand for *I. grandis* is linked to its valuable attributes, particularly the medicinal properties of its roots. However, unsustainable exploitation without appropriate conservation measures has led to population declines, posing significant risks to its long-term survival.

Addressing this urgent conservation challenge requires focused protection and management of wild *I. grandis* populations. This requires comprehensive study of its distribution range and assessment of climate change impacts on both habitat suitability and geographic distribution. As global temperatures rise and weather patterns become increasingly unpredictable, the essential habitat conditions required for *I. grandis* survival and reproduction may undergo significant alterations. Therefore, it is very important to study the species' response to these ecological changes in order to predict the future distribution of the species and, especially, to identify vulnerable areas.

The research objectives related to the conservation of *I. grandis* are multifaceted and comprehensive. They encompass various aspects of assessing the distribution of the species, understanding its ecological requirements, and developing strategies for its sustainable management. The main objectives of this research are as follows:

1. Changes in the distribution area: The first objective is to analyze the changes in the distribution area of *I. grandis* resulting from

environmental changes. By studying contributing factors such as land-use patterns, climate variability, and anthropogenic influences, we can gain insights into the drivers of distributional shifts and assess their overall impact on species' population dynamics.

2. Assessing habitat suitability: This objective is focused on evaluating the suitability of habitats for *I. grandis* under current and future climate scenarios. By applying advanced modeling methods, researchers can integrate climate data, species distribution areas, and environmental factors to develop habitat suitability models. These models will help identify areas where the species may thrive or face challenges due to climate-related factors. Understanding the habitat requirements and preferences of *I. grandis* is crucial for effective conservation planning and implementing targeted management actions.

3. Identifying key ecological factors: This objective is focused on identifying the key ecological factors that influence the range change and distribution of *I. grandis*. Researchers can use statistical analyses and climate modeling approaches to determine the relative significance of variables such as temperature, precipitation, soil characteristics, and topography. By quantitatively assessing the relationship between these factors and patterns of species distribution, we can gain a comprehensive understanding of the ecological niche of *I. grandis* and its sensitivity to environmental changes.

4. Conservation measures and resource management: The final objective is to develop conservation strategies and management recommendations based on the results of the research. This involves integrating scientific knowledge with practical considerations to ensure the sustainable use of *I. grandis* resources and the conservation of its natural habitat and population. Measures for nature conservation may include the establishment of protected areas, the implementation of sustainable harvesting practices, actions aimed at the restoration of natural habitats, and initiatives to engage the public in conservation efforts. In addition, guidelines for the development and utilization of resources may be formulated to promote

responsible practices that ensure a balance between the long-term conservation of *I. grandis* and economic benefits.

By achieving the objectives of this study, we can provide a comprehensive understanding of the distributional shifts, ecological requirements, and vulnerability of *I. grandis* to climate change. This knowledge serves as a foundation for evidence-based decision-making, policy development, and the implementation of effective conservation measures. As a result, this study aims to contribute to the protection of the future of *I. grandis* populations, support the sustainable use of resources, and ensure the ecological integrity of its natural habitats.

Materials and Methods

Georeferenced data reflecting the distribution of *I. grandis* species were obtained from field studies and online databases such as INaturalist (<https://www.inaturalist.org/>) and Plants and lichens of Russia and neighboring countries: Open Online Galleries and Plant Identification Guide (<https://www.plantarium.ru>). In total, 20 georeferenced data points for *I. grandis* were downloaded. To model the distribution of the species, bioclimatic data obtained from the WorldClim database (<http://www.worldclim.org>) includes nineteen climatic variables (Table 1). To more accurately depict the potential distribution of *I. grandis*, soil data from the World Soil Database (82 soil parameters) were integrated with bioclimatic data (19 climatic variables). Using the Extract by Mask tool in ArcGIS 10.8, the climatic data were clipped and extracted, preserving the required data range, and finally

converted to ASCII format. The georeferenced data were uploaded into MaxEnt 3.4.4 (Phillips et al., 2006; Phillips & Dudík, 2008) and evaluated using the Jackknife test with bioclimatic, soil, and elevation data. The resulting models were calibrated using 75% of the available data as training data for each species, with the remaining 25% used as test data to validate the model. The Bootstrap method was performed with 10 repetitions, a maximum of 5000 iterations, and standard selected parameters. The performance of the model was evaluated by calculating the area under the receiver operating characteristic curve (AUC), where models with an AUC value greater than 0.7 were considered satisfactory for our study (Phillips et al., 2006; Phillips & Dudík, 2008). MaxEnt is a multivariate approach that evaluates species distribution by finding the probability distribution of maximum entropy, taking into account the constraints that represent our incomplete information about distribution. Overall, an AUC < 0.7 indicates low model accuracy, while prediction results with an AUC between 0.7 and 0.9 can be considered acceptable, and an AUC > 0.9 indicates that the prediction results are highly accurate and can be used for further analysis.

Future climate scenarios. Two Representative Concentration Pathway (RCP) climate scenarios (RCP 8.5) from the Intergovernmental Panel on Climate Change (IPCC, 2013) Fifth Assessment Report (AR5) were downloaded for 2050 from the WorldClim online database (www.worldclim.org).

Table 1.

Bioclimatic Variables from Worldclim Bioclimatic data

Environmental Variable	Description	Unit
Bio1	Annual mean temperature	°C
Bio2	Mean diurnal range (mean of monthly (max temp – min temp))	°C
Bio3	Isothermality (Bio2/Bio7) (×100)	-
Bio4	Temperature seasonality (standard deviation ×100)	-
Bio5	Maximum temperature of the warmest month	°C
Bio6	Minimum temperature of the coldest month	°C

Environmental Variable	Description	Unit
Bio7	Temperature annual range (Bio5–Bio6)	°C
Bio8	Mean temperature of the wettest quarter	°C
Bio9	Mean temperature of the driest quarter	°C
Bio10	Mean temperature of the warmest quarter	°C
Bio11	Mean temperature of the coldest quarter	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of the wettest month	mm
Bio14	Precipitation of the driest month	mm
Bio15	Precipitation seasonality (coefficient of variation)	-
Bio16	Precipitation of the wettest quarter	mm
Bio17	Precipitation of the driest quarter	mm
Bio18	Precipitation of the warmest quarter	mm
Bio19	Precipitation of the coldest quarter	mm

Results and Discussion

Georeferenced data reflecting the geographic distribution of *Inula grandis*, commonly known as Yellow Inula, were obtained from several international open biological databases that include spatial distribution data of plant species across Central Asia. Based on the databases, these georeferenced data, which indicate the geographic regions where the species

is known to occur or be distributed, were subsequently processed using ArcGIS 10.8 Geographic Information System software of the Esri. The ArcGIS interface allowed for the mapping of the approximate overall range and size of areas where *I. grandis* is currently likely to occur, based on existing geographic data of the locations of the points (Figure 1).

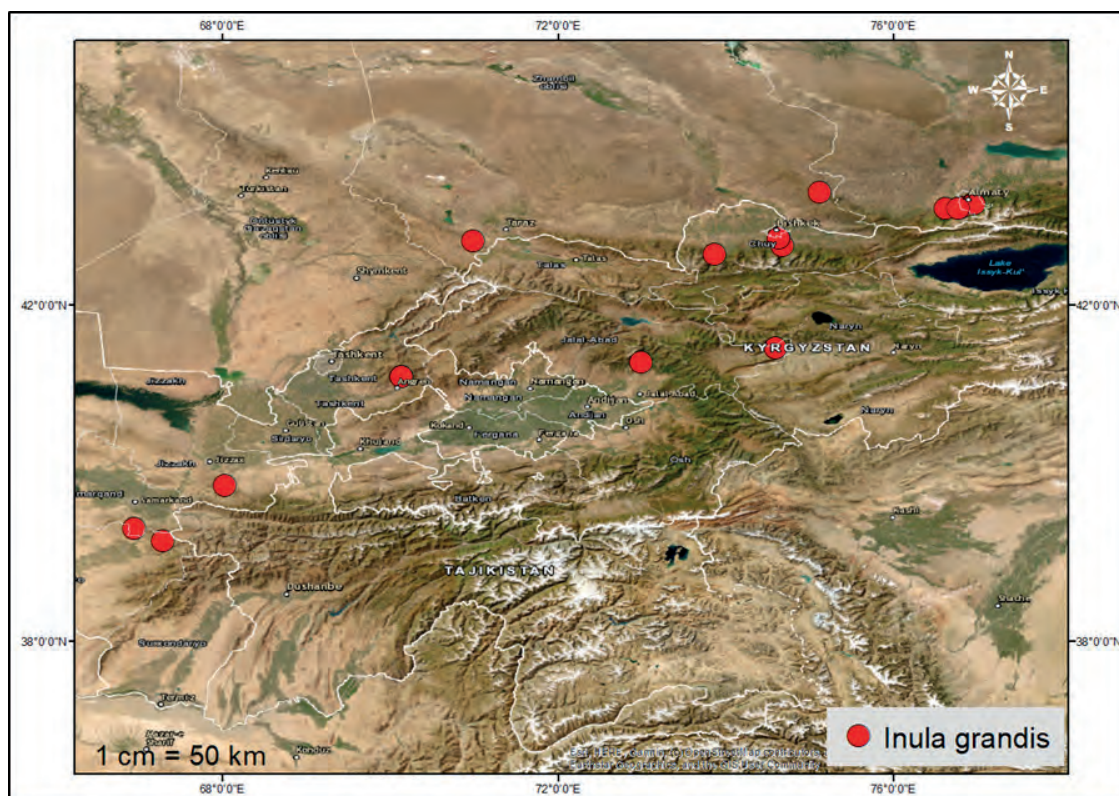


Figure 1. Known distribution areas of Yellow elecampane.

We conducted a species bioclimatic modeling for yellow elecampane using 19 bioclimatic variables with random algorithms. To identify the key climatic factors that define the range of yellow elecampane, we employed the Jackknife test, which was applied to the trained random model to assess the variable importance. The Jackknife test systematically evaluates the contribution of each variable to the model's

predictive performance by repeatedly training the model with and without each variable. Predictive efficiency was assessed using an independent test data set. The results of the Jackknife test identified four bioclimatic variables with high variable importance for yellow elecampane (Figure 2).

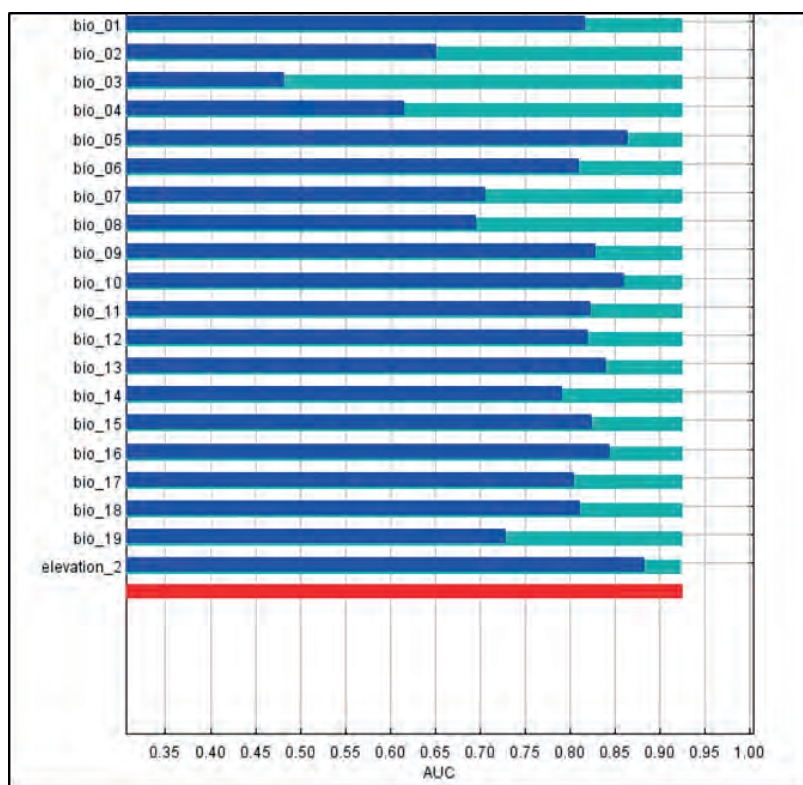


Figure 2. Jackknife test results for the importance of bioclimatic variables for yellow elecampane.

When each of these four variables was excluded from the individual models, the resulting AUC scores were significantly lower compared to models where other variables were excluded. This indicates that the maximum and average temperatures during the hottest periods, as well as precipitation levels during the hottest and wettest intervals, provide critical signals regarding the climatic boundaries of yellow elecampane. Notably, these important variables describe the temperature and humidity conditions during extreme periods of the hot season, which reflect the species' physiological tolerance and habitat requirements, dependent on sufficient precipitation during its peak heat tolerance and active growth phases. The identification of these four bioclimatic variables as key

factors in determining the potential distribution of yellow elecampane confirms their ecological significance and provides insight into the climatic controls shaping its distribution boundaries. Based on these results, further research can be conducted to understand how yellow elecampane will respond to future climate change and potentially project its future distribution. Additionally, topographic factors are also highly important for yellow elecampane. The species distribution modeling identified four key ecological factors that define the ecological niche of yellow elecampane, which are primarily located in the foothills and lower slopes of the Pamir-Alay and Tien Shan mountain ranges in Uzbekistan (Figure 3).

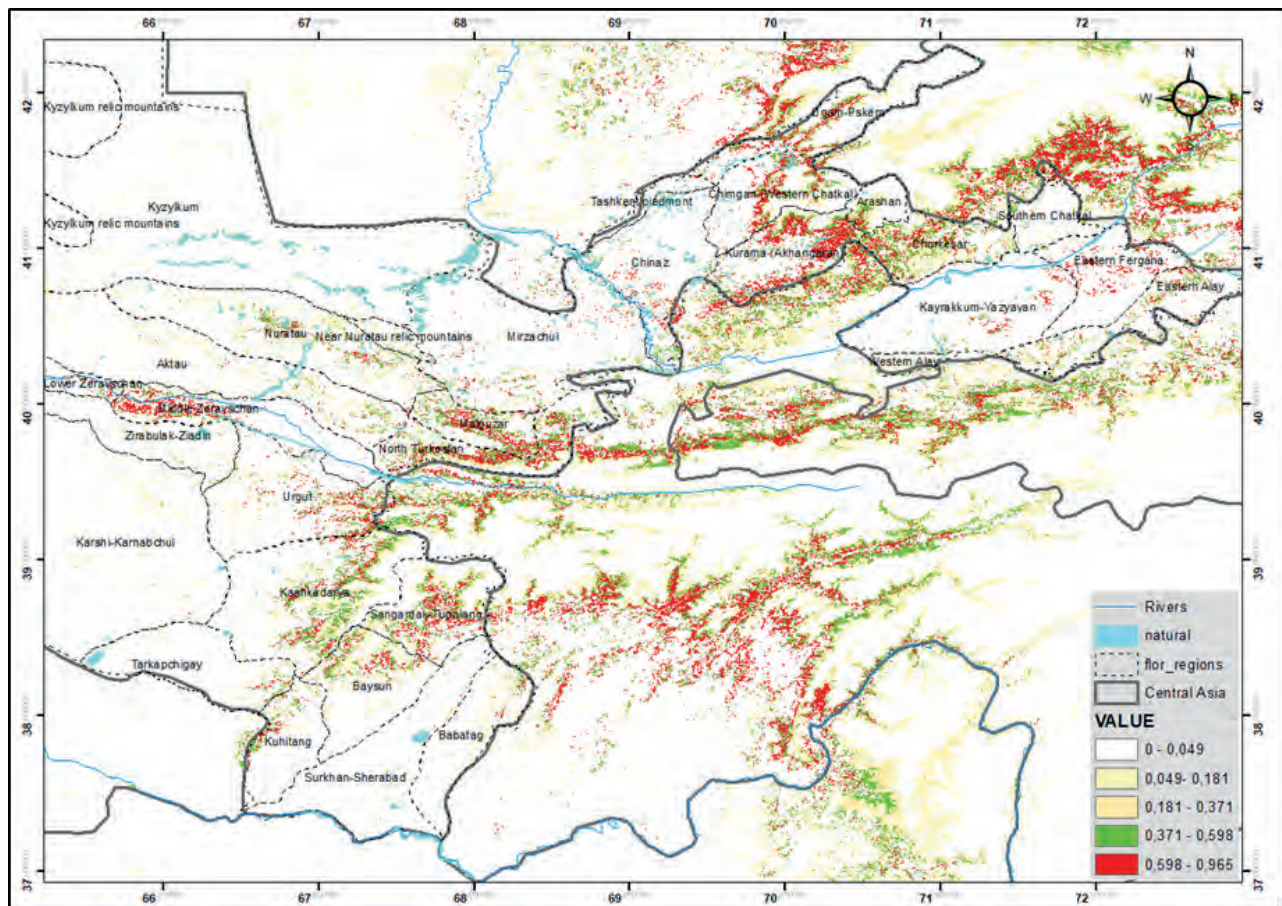


Figure 3. Suitable ecological habitats for yellow elecampane. The most suitable ecological habitats are represented in red (0.598–0.965).

Specifically, these suitable areas include the regions of Tashkent, Jizzakh, Samarkand, Kashkadarya, Surkhandarya, Andijan, and Fergana. From the perspective of Uzbekistan's botanical-geographical regions (Tojibaev et al., 2016), the most suitable habitats encompass the areas of Qurama, Chimyon, Ugom-Piskom, Molguzar, Northern Turkestan, Urgut, Kashkadarya, Boysun, Sangardak-Topalang, Central Zarafshan, Kohitang, Bobotog, as well as Eastern Fergana and Eastern Alai regions. These regions represent the primary habitats that correspond to the climatic factors - temperature, precipitation, and elevation - defining the species distribution of the model. Considering that modeling and field studies show that these areas provide

the most suitable environmental conditions for the populations of yellow elecampane, we propose creating a series of managed plantations in suitable locations across the identified regions. These plantations will help expand the range of yellow elecampane and provide additional reserves to strengthen its long-term survival in Uzbekistan, especially under the pressure of habitat loss and fragmentation. After the establishment of these plantations, regular monitoring and maintenance will be necessary to support the growth of populations in these new areas over time. The reliability of the obtained results is very high, with AUC < 9 (Figure 4).

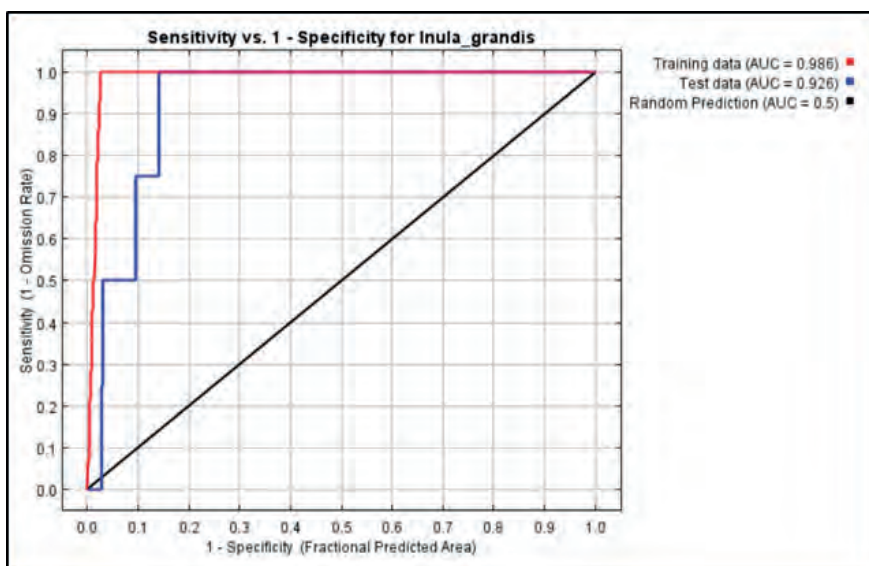


Figure 4. Graph showing the reliability level of the Maxent model.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) of 2013 provided valuable information on the potential impacts of climate change on various species and ecosystems. The report utilized Representative Concentration Pathway (RCP) climate scenarios, particularly RCP 8.5, to project potential changes in environmental conditions for species by 2050. Maxent analysis of yellow elecampane identified the key factors

(bio12), isothermicity (bio3), annual average temperature (bio1), and temperature seasonality (bio4). These variables were used to develop species distribution models and predict the potential distribution of yellow elecampane under future climate scenarios. The projected changes in suitable ecological conditions for yellow elecampane based on the RCP 8.5 climate scenario from the IPCC AR5 report are depicted (Figure 5).

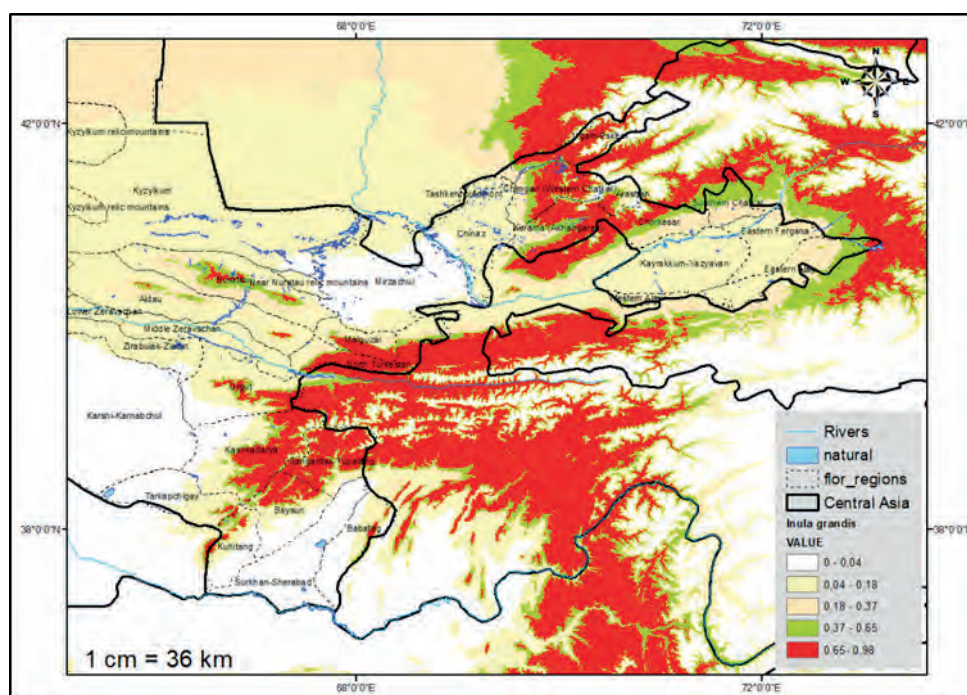


Figure 5. Predicted distribution area of yellow elecampane in suitable habitats by 2050.

Conclusions

In conclusion, our study on the geographic distribution of *Inula grandis* and the climatic factors affecting it provides valuable insights into the potential and habitat of the species responses to climate change. Through the analysis of coordinate data and the use of advanced geographic information system (GIS) software, we successfully mapped the estimated range and extent of areas where yellow elecampane may occur. Bioclimatic modeling and Jackknife testing identified four key variables significantly influencing species distribution: maximum temperature of the hottest month, average temperature of the hottest quarter, precipitation of the hottest month, and precipitation during the wettest quarter. These variables play a crucial role in defining the climatic boundaries of yellow elecampane, highlighting its preference for high heat tolerance and sufficient precipitation during its active growing period. Furthermore, our distribution model indicated that yellow elecampane primarily grows in the foothills and lower slopes of the Pamir-Alay and Tian Shan mountain ranges in Uzbekistan. Distinct regions such as Tashkent, Jizzakh, Samarkand, Kashkadarya, Surkhandarya, Andijan, and Fergana were identified as the most suitable habitats for the species. Based on these findings, we propose the establishment of managed plantations

in these suitable areas to expand the range of yellow elecampane and enhance its long-term conservation efforts under the pressure of habitat loss and fragmentation. Considering the potential impacts of climate change, our research aligns with the projections in the IPCC AR5 report. Using Representative Concentration Pathway (RCP) climate scenarios, we identified annual precipitation, isothermicity, annual average temperature, and temperature seasonality as the main climatic factors influencing yellow elecampane. Based on the RCP 8.5 scenario, which represents high greenhouse gas emissions, our models predict changes in suitable ecological conditions for the species in the future. From the perspective of these findings, conducting additional research and monitoring is crucial to better understand and manage the response of yellow elecampane to climate change. By implementing the proposed plantation strategy and regularly monitoring new populations, we can contribute to species conservation and mitigate the potential impacts of climate change on its habitat. Our research serves as a foundation for future conservation efforts and emphasizes the importance of proactive measures to protect yellow elecampane and its ecological niche.

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THE CURRENT STATUS OF WOODY SPECIES OF THE *ROSACEAE* JUSS. FAMILY SPREADING IN THE MOUNTAIN XEROPHYTIC AND STEPPE VEGETATION OF THE JULFA REGION

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Abstract. *The article provides information on the current status of woody species of the Rosaceae Juss. family in the mountain-xerophytic and steppe vegetation of the Julfa region. Based on existing literature and conducted research, the taxonomic composition, life forms, ecological groups, geographical range types, and classes of the woody species of the Rosaceae family in the mountain-xerophytic and steppe vegetation of the Julfa region have been studied. According to our research, when characterizing the woody species of the Rosaceae family in the mountain-xerophytic and steppe zones of the Julfa region by genera, it was found that Rosa comprises 22 species (43.1%), Prunus 8 species (15.7%), Crataegus 5 species (9.8%), Pyrus 5 species (9.8%), Sorbus 4 species (7.8%), Cotoneaster 2 species (3.9%), Spiraea 2 species (3.9%), and Malus, Rubus, and Pyracantha are represented by 1 species (1.96%) each.*

Shrubs, particularly the woody species of the Rosaceae family, play an important role in the structure of the flora of the Julfa region. They are part of shrub steppe areas, form independent groups, and create unique formations. As the conducted research shows, species of the Rosa L. genus are predominant in the regional flora. These species form part of the shrub steppes, create independent groups, and form unique formations.

Keywords: *mountain xerophyte, steppe, taxonomic composition, life form, ecological group, areal class*

INTRODUCTION

The Nakhchivan Autonomous Republic stands out from other botanical-geographical regions of Azerbaijan and the Caucasus due to its rich flora, which has always attracted attention. The mountainous nature of the autonomous republic results in its plant cover being distinctly divided into different zones. One such zone is the area of the Julfa district, which differs from other areas due to its plant cover and fertile soil. A large number of studies have been conducted on the composition, structure, and dynamics of the plant cover of the Julfa district. However, little attention has been paid to the characteristics of the mountain xerophyte and steppe vegetation in the region.

The mountainous terrain of the Nakhchivan AR has led to the easy division of the region's plant cover into distinguishable zones. The research conducted by us allows for the identification of important features typical of the woody species of the *Rosaceae* family in the mountain xerophyte and steppe zones of the Julfa district. Shrub plants, especially woody species of the *Rosaceae* family, play a significant role in the structure of the mountain xerophyte and steppe complex.

Material and Method

The research has been ongoing since 2019. The primary materials used in the study are references to literature sources and field data

collected during field research. The study object is the mountain xerophyte and steppe zones of the Julfa district, and the study material is the woody species of the *Rosaceae* family. The identification of species was carried out using sources such as A.M. Asgarov's "Flora of Azerbaijan" (Askerov, 2016), and E. Sh. Ibrahimov, M. Z. Piriyeu, D. Sh. Qanbarov's "Woody Plants of the *Rosaceae* Family in the Nakhchivan Autonomous Republic" (2011). The most recent taxonomic changes were made based on the World Flora Online database (<https://about.worldfloraonline.org/>).

Discussion and Results

One of the main families in the flora of the

Nakhchivan Autonomous Republic is the *Rosaceae* family. The woody and shrub plants of this family are represented by 116 species belonging to 23 genera. The research revealed that the woody species of the *Rosaceae* family in the region are characterized by 79 species belonging to 12 genera. Based on personal field research, it was determined that the woody species of the *Rosaceae* family in the mountain xerophyte and steppe zones of the Julfa district belong to 51 species from 10 genera of the family. The taxonomic composition and floristic analysis of the woody species of the *Rosaceae* family found in the mountain xerophyte and steppe zones of the studied area are presented in Table 1 (Babayeva, 2020).

Table 1

Taxonomic composition and floristic analysis of the woody species of the *Rosaceae* family found in the studied area

S/№	Species name	Life forms	Ecological groups	Geographical area classes
1	<i>Cotoneaster melanocarpus</i>	nanophanerophytes	xerophytes	Paelearctic
2	<i>C. multiflorus</i>	nanophanerophytes	xerophytes	Central Asia
3	<i>Crataegus monogyna</i>	microphanerophytes	mesoxerophytes	Europe
4	<i>C. meyeri</i>	microphanerophytes	mesoxerophytes	Front Asia
5	<i>C. orientalis</i>	microphanerophytes	mesoxerophytes	Eastern Mediterranean
6	<i>C. pontica</i>	microphanerophytes	mesoxerophytes	North Iran
7	<i>C. pseudoheterophylla</i>	microphanerophytes	mesoxerophytes	Front Asia
8	<i>Malus orientalis</i>	microphanerophytes	mesophytes	Caucasus
9	<i>Prunus araxina</i>	nanophanerophytes	xerophytes	Atropatan
10	<i>P. communis</i>	microphanerophytes	mesophytes	Front Asia
11	<i>P. divaricata</i>	mesophanerophytes	mesophytes	Eastern Mediterranean
12	<i>P. fenzliana</i>	microphanerophytes	xerophytes	Front Asia
13	<i>P. incana</i>	nanophanerophytes	xerophytes	Iran
14	<i>P. mahaleb</i>	microphanerophytes	mesophytes	Mediterranean Sea
15	<i>P. microcarpa</i>	nanophanerophytes	xerophytes	Iran
16	<i>P. nairica</i>	nanophanerophytes	xerophytes	Atropatan
17	<i>Pyracantha coccinea</i>	nanophanerophytes	mesophytes	Eastern Mediterranean
18	<i>Pyrus medvedevii</i>	mesophanerophytes	xerophytes	Atropatan
19	<i>P. oxyprion</i>	mesophanerophytes	xerophytes	Atropatan
20	<i>P. raddeana</i>	microphanerophytes	mesoxerophytes	Atropatan
21	<i>P. salicifolia</i>	mesophanerophytes	mesophytes	Iran

S/№	Species name	Life forms	Ecological groups	Geographical area classes
22	<i>P. syriaca</i>	mesophanerophytes	mesophytes	Eastern Mediterranean
23	<i>Rosa buschiana</i>	nanophanerophytes	mesophytes	Caucasus
24	<i>R. boissieri</i>	nanophanerophytes	mesophytes	Asia Minor
25	<i>R. chomutoviensis</i>	nanophanerophytes	mesophytes	Unknown
26	<i>R. canina</i>	nanophanerophytes	mesophytes	Western Palearctic
27	<i>R. corymbifera</i>	microphanerophytes	mesophytes	Europe
28	<i>R. floribunda</i>	nanophanerophytes	mesoxerophytes	Asia Minor
29	<i>R. foetida</i>	nanophanerophytes	mesophytes	Front Asia
30	<i>R. haemisphaerica</i>	nanophanerophytes	xeromesophytes	Front Asia
31	<i>R. karjaginii</i>	nanophanerophytes	mesoxerophytes	Atropatan
32	<i>R. kazarjanii</i>	nanophanerophytes	mesophytes	Atropatan
33	<i>R. marschalliana</i>	nanophanerophytes	mesophytes	Caucasus
34	<i>R. multiflora</i>	microphanerophytes	mesoxerophytes	Eastern Mediterranean
35	<i>R. sachokiana</i>	nanophanerophytes	xerophytes	Albania
36	<i>R. sosnovskyana</i>	nanophanerophytes	mesophytes	Caucasus
37	<i>R. subafzaliana</i>	nanophanerophytes	mesoxerophytes	Europe
38	<i>R. rapinii</i>	nanophanerophytes	xerophytes	Front Asia
39	<i>R. spinosissima</i>	nanophanerophytes	mesoxerophytes	Southern Palearctic
40	<i>R. teberdensis</i>	nanophanerophytes	mesophytes	Caucasus
41	<i>R. tomentosa</i>	nanophanerophytes	mesophytes	Europe
42	<i>R. tschatyrdagi</i>	nanophanerophytes	xerophytes	Unknown
43	<i>R. villosa</i>	nanophanerophytes	mesophytes	Eastern Mediterranean
44	<i>R. zangezura</i>	nanophanerophytes	mesophytes	Atropatan
45	<i>Rubus anatolicus</i>	nanophanerophytes	mesophytes	Caucasus
46	<i>Spiraea crenata</i>	nanophanerophytes	mesoxerophytes	Pontic Sarmatian
47	<i>S. hypericifolia</i>	nanophanerophytes	mesoxerophytes	Pontic Sarmatian
48	<i>Sorbus graeca</i>	microphanerophytes	mesoxerophytes	Eastern Mediterranean
49	<i>S. persica</i>	microphanerophytes	mesoxerophytes	Iran
50	<i>S. luristanica</i>	microphanerophytes	xeromesophytes	Iran
51	<i>S. roopiana</i>	microphanerophytes	mesophytes	Iran

The classification of life forms demonstrates, on one hand, the ways in which different species of plants adapt to the same conditions, and on the other hand, the possibility of similarities in these adaptation methods in plants from unrelated species, genera, and families. Therefore, the classification of life forms cannot coincide with the conventional systematics

classification, which is based on the structure of reproductive organs and reflects the common ancestry of plants. The classification of life forms is based on the structure of vegetative organs.

Taking the above into account, the life forms of woody species belonging to the *Rosaceae* family in the mountainous xerophytic and

steppe zones of the Julfa region are grouped into three subtypes of phanerophytes. Mezophanerophytes are trees with a height of 8-30 meters, microphanerophytes are trees and shrubs with a height of 2-8 meters, and nanophanerophytes are shrubs with a height of less

than 2 meters. Among the woody species of the *Rosaceae* family in the mountainous xerophytic and steppe zones of the Julfa region, 30 species are nanophanerophytes, 16 are microphanerophytes, and 5 species are mezophanerophytes (Babayeva, 2022).

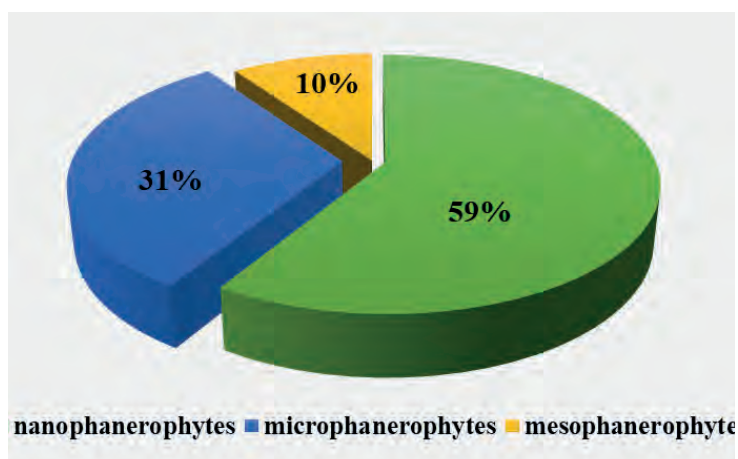


Figure 1. Life forms of woody species belonging to the *Rosaceae* family of the mountain-xerophyte and steppe zone of Julfa region flora

Water is important as an ecological factor in spreading plants over wide areas under different climatic conditions, spreading them in different areas and forming different groups. Plants are divided into different ecological groups. Spreading of woody species of the *Rosaceae* family of Nakhchivan MR by ecological groups was carried out according to Shennikov's classification system.

Mesophytes occupy an intermediate position between hydrophytes and xerophytes in their relation to moisture and their requirements. Mesophytic plants are mainly forest, shrub, subalpine, alpine plants. Xerophytic species are plants that spread mainly in dry areas

and have acquired various adaptations to moisture deficiency. This group of plants includes desert, dry steppe, thorn sparse forest, rocky, etc. refers to the plants common in the areas. There are also plants that are mesophytic in origin and lead a relatively xerophytic lifestyle by adapting to their ecological environment. These plants are mesoxerophytic plants. Xeromesophytes occupy an intermediate position between xerophytes and mesoxerophytes. They are mostly found in forest clearings and sparse bush areas, and especially in the north-west and south-west of the mountain slopes (Babayeva, 2020).

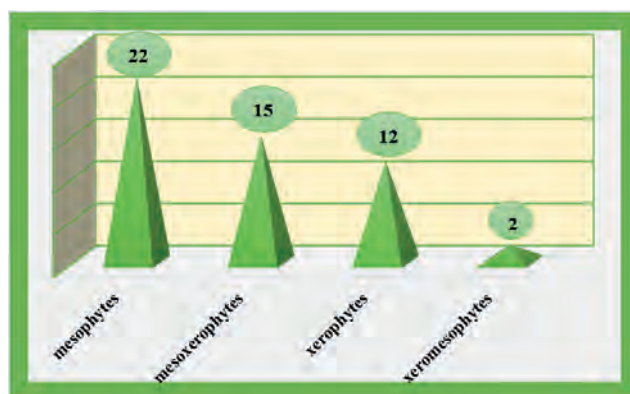


Figure 2. Ecological groups of woody species belonging to the *Rosaceae* family of the mountain-xerophyte and steppe zone of Julfa region flora

From diagram 2, it is known that in the studied area there are 22 mesophytes, 12 xerophytes, 15 mesoxerophytes, and 2 xeromesophytes (Figure 2).

Areal types of species highlight the relationship between the flora of the studied region and that of the larger surrounding areas, thereby facilitating an exploration of historical species migration routes. Through a review of available literature and our own field research, we have identified that the woody species of

the *Rosaceae* family in the mountain-xerophytic and steppe zones of the Julfa region belong to various areal types and classes. This classification allows us to trace the migration routes of these species to the area.

Based on zonal and regional principles, the woody species of the family spreading in the studied area were analyzed in 4 types of geographical areas and 15 areal classes (Ganbarov, 2020)

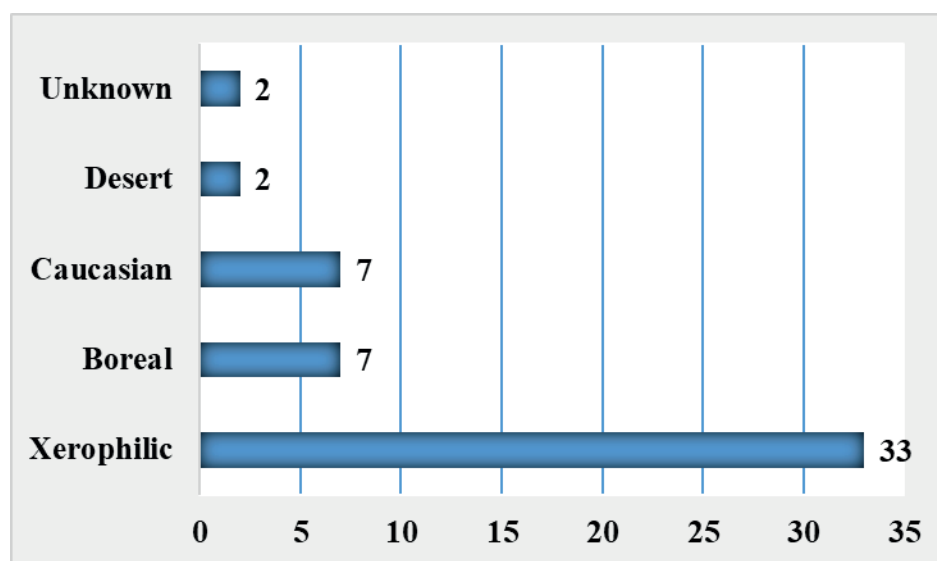


Figure 3. Areal types of woody species belonging to the *Rosaceae* family of the mountain-xerophyte and steppe zone of Julfa region flora

As can be seen from the given diagram, the Xerophilic areal type includes 33 species, the Caucasian areal type-7, the Boreal areal type-7, and the Desert areal type 2 species. The area type of two species is unknown. (Figure 3).

As a result of the conducted research, the taxonomic composition of 51 woody species from the mountain-xerophytic and steppe zones of the Julfa region, which belong to the *Rosaceae* family, was identified. These species were categorized based on their life forms, ecological groups, and areal classes. The findings of this research provide a significant scientific foundation for further studies on the flora of the mountain-xerophytic and steppe zones in the Julfa district.

Conclusions

- ✓ As a result of the conducted research, it was determined that the flora of Julfa region is characterized by 51 species belonging to 10

genera of woody plants belonging to the *Rosaceae* family of the mountain-xerophyte and steppe zone.

- ✓ When the woody species of the *Rosaceae* family of the studied area were characterized by genera, it was found that, *Rosa* - 22 (43,1%), *Prunus* 8- (15,7%), *Crataegus* - 5 (9,8%), *Pyrus* - 5 (9,8%), *Sorbus* - 4 (7,8%), *Cotoneaster* 2 (3,9%), *Spiraea* 2 (3,9%), *Malus*, *Rubus* and *Pyracantha* (1,96%) type is found.
- ✓ The analysis of life forms shows that woody species belonging to the *Rosaceae* family of the mountain-xerophyte and steppe zone of Julfa district flora are grouped into 3 subtypes of phanerophytes. It was found that mesophanerophytes are represented by 5 (13%), microphanerophytes by 16 (32%) and nanophanerophytes by 30 (55%) species. According to their ecological groups, mesophytes are represented by 22 (43,13%),

xerophytes 12 (23,52%), mesoxerophytes 15 (29,41%), xeromesophytes 2 (3,92%) species.

- ✓ Among the woody plants belonging to *Rosaceae* family of mountain-xerophyte and steppe zone of Julfa district flora, Xerophyll areal type-33, Caucasian areal type-7, Boreal areal type-7 and Sahara areal type include 2 species. The area type of two species is unknown.

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INVESTIGATION OF THE RESISTANCE OF GRAPE GENOTYPES TO *PLASMOPARA VITICOLA* PATHOGENS

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Abstract. *Grape (Vitis vinifera L.) is a major agricultural crop with significant economic value worldwide, including Azerbaijan. Grapevines in Azerbaijan face significant challenges from downy mildew (Plasmopara viticola), a fungal disease that affects grape yield and quality. This study aimed to evaluate the resistance of 37 grapevine varieties to downy mildew under natural field conditions. The results revealed two main genotype clusters: 13 varieties were classified as tolerant (scoring 3-3.5), while 24 varieties were classified as susceptible (scoring 4-4.5). No varieties were found to be highly resistant or highly susceptible. The evaluation process utilized a 5-point scale to assess disease severity on leaves and clusters. Findings from this study are crucial for identifying grapevine varieties with improved resistance to downy mildew, aiding in the development of more resilient grape cultivars. These results have significant practical implications for enhancing grapevine production and mitigating the impacts of fungal diseases in viticulture.*

Keywords: *Vitis, downy mildew, pathogen, assessment, fungus*

Introduction

Grapevine (*Vitis rupestris*) belongs to the *Vitaceae* Juss. family, with *Vitis* being the last genus among the 11 genera within this family. The majority of species in this family consist of wild forms. In Azerbaijan, approximately 600 indigenous and introduced grape varieties have been cultivated, of which around 400 are local varieties (Salimov et al., 2022).

Globally, grapevine (*Vitis vinifera* L.) is one of the most extensively cultivated and economically significant crops. It currently holds great importance in the national economy, and the efficient and sustainable utilization of grape genetic resources is crucial for ensuring the

intensive development of this sector through the creation of new high-yielding and resilient varieties.

It is important to highlight that achieving significant success in viticulture, producing environmentally friendly products, and addressing ecological issues in vineyards require breeders to focus their research on developing grape varieties that are resistant to diseases, pests, and abiotic stresses. Additionally, it is essential to enhance the resistance of existing grape cultivars.

The molecular-level investigation of local grapevine varieties and forms, along with the assessment of their resistance to major

diseases encountered under field conditions and the study of resistance-related genes, holds significant theoretical and practical importance. Enriching the varietal composition of vineyards, replacing low-yielding and poor-quality grape varieties with new, more productive and high-quality ones, and ensuring the efficient and sustainable utilization of grape genetic resources are crucial for food security, as well as for increasing grape and grape-derived product production in the country (Mokhtar et al., 2015;

Shikhlinski et al., 2019).

In recent years, fungal diseases in vineyards, particularly in newly established vineyards and nurseries, have become the most critical threats to grape production, significantly reducing both yield and quality. According to data obtained from the State Statistical Committee of the Republic of Azerbaijan, statistical information on grape yield across the country for the period 2021–2024 is presented below.

Table 1

Grape Yield in Azerbaijan During the Period of 2021–2024

Years	2021	2022	2023	2024
Fertility of grape	98.2	102.7	113.3	102.2

In the climatic conditions of Azerbaijan, grapevines are predominantly affected by fungal diseases such as powdery mildew (*Erysiphe necator* syn. *Uncinula necator*), downy mildew (*Plasmopara viticola*), gray mold (*Botrytis cinerea* Pers.), and anthracnose (*Gloeosporium ampelophagum* Sacc.) (Salimov et al., 2022). These fungal pathogens restrict grapevine growth and cause significant yield losses.

Currently, one of the primary challenges in agriculture is protecting crops from diseases and pests to enhance productivity and improve quality (Məcidli et al., 2019). Viticulture holds a substantial share among agricultural crops in Azerbaijan and is also considered one of the most economically significant sectors. The damage and losses inflicted on agricultural crops by phytopathogenic organisms are exceedingly high (Feng et al., 2018).

The causative agent of the disease is the spores of the *Plasmopara viticola* fungus. This pathogen affects all above-ground parts of the grapevine, including leaves, green shoots, buds, flowers, and berries. A key symptom of the disease is the appearance of oily spots on the upper surface of the leaves. Under humid conditions, when temperatures exceed 12°C, a white, mildew-like coating forms on the underside of the leaves. Over time, infected leaf tissues turn reddish-brown or darken, eventually

drying out. Affected buds, flowers, and ovaries also wither and fall off (Salimov et al., 2022; Məcidli et al., 2019).

There is a common misconception that newly developed berries are not susceptible to downy mildew and that the disease poses minimal risk to fruit. However, experimental evidence indicates that in warm, humid conditions, berries develop sunken, dirty bluish-gray spots, leading to wrinkling and premature shedding. As a result, the grape cluster loses its shape and weight. Downy mildew also affects the shoots, forming lesions that hinder the ability of leaves to synthesize organic matter. This prevents the accumulation of nutrients, causing the shoots to remain underdeveloped and ultimately freeze and perish during the winter (Shikhlinski et al., 2014).

Long-term studies have shown that the disease spreads rapidly in rainy conditions at temperatures of 9–10°C and in dry weather when temperatures range between 22–26°C. Observations confirm that downy mildew develops when temperatures are between 11–13°C with high humidity. The latent period of the fungus varies depending on temperature fluctuations, and the development of the disease is restricted under conditions of high temperatures (above 30°C) and low humidity.

During the evaluation process, samples

showing a tolerant response were selected from the tested specimens. Subsequently, through intra-specific and inter-specific crosses, it becomes possible to obtain new high-quality grape varieties that are resistant to diseases and pests.

Materials and Methods

The resistance of grape varieties and forms to downy mildew was assessed using the method developed by H.M. Shikhlinski (2016) and the 5-point scale refined by I.N. Naydenova (P.N. Nedov, 1985). The phytopathological evaluation of grapevines was carried out under natural field conditions.

0 points: Immune - no signs of the disease are observed on the leaves.

1 point: Highly resistant - small, sporulating spots are observed on the leaves.

2 points: Resistant - weak sporulating necrotic groups of cells are found between the leaf veins.

3 points: Tolerant (resistant) - small, oily, mildew spots are found, surrounded by necrotic areas. Due to the weak development of fungal spores, the growth of the spots is limited. Leaves do not fall off.

4 points: Susceptible - numerous large oily spots with sporulating areas are found on the leaves. In some cases, leaf drop is observed.

5 points: Highly susceptible - large oily spots covering the leaf surface with a significant amount of spores. In severe cases, the leaves fall off completely.

The phytopathological evaluation of natural infection of grape clusters with downy mildew was conducted as follows:

0 points: No damage observed on the clusters.

1 point: A few individual berries show a greyish coating.

2 points: Infection of berries in the clusters ranges from 1% to 10%.

3 points: Infection of berries in the clusters ranges from 10% to 30%.

4 points: Infection of berries in the clusters ranges from 30% to 50%, with visible damage on the berries.

5 points: Infection of berries in the clusters exceeds 50%, with cracks and damage observed on the berries.

The evaluation results of the studied samples were grouped using Cluster Analysis. This analysis allows us to visually observe the clustering of genotypes. Cluster analysis was performed using the UPGMA method and the Euclidean distance index in the PAST statistical software package.

Results and Discussion

Phytopathological evaluation of the natural infection of 37 grape varieties with downy mildew was conducted at the Absheron Scientific-Research Base. The results of the phytopathological evaluation of the grape varieties under natural conditions are presented in Table 2.

Table 2

The results of evaluating the resistance levels of the studied grape varieties to *Plasmopara viticola* Berk. & Berl. & de Toni fungus are as follows.

№	Name of the grape variety	Resistance in the cluster, rated by points	№	Name of the grape variety	Resistance in the cluster, rated by points	№	Name of the grape variety	Resistance in the cluster, rated by points
1	Madrasa	3	14	Nakhchivan gulabisi	3	27	Agh Aldara	4
2	Alikhanli gara uzumu	3	15	Marandil	3	28	Gizil uzum Absheron	3
3	Gara shani	3	16	Banovshayi	4	29	Zeynaddin	4

No	Name of the grape variety	Resistance in the cluster, rated by points	No	Name of the grape variety	Resistance in the cluster, rated by points	No	Name of the grape variety	Resistance in the cluster, rated by points
4	Agh Khalili	3	17	Agh kurdashi	4	30	Uzunbashli	4
5	Hachabash	3	18	Nakhchivan huseynisi	3	31	Girmizi kishmish Nakhchivan	3
6	Mahmudu	4	19	Kechiamcayi	3	32	Irigila	4
7	Bayanshira az nokhudlayan	4	20	Gara qush urayi	4	33	Arayatli	4
8	Gazan dayi	3	21	Rishbaba	3	34	Irigila kishmish	3
9	Khatmi	4	22	Kharci	3	35	Marmari	3
10	Tabrizi	3	23	Misgali	4	36	Bayanshira	3
11	Sari kishmish	3	24	Gizil uzum Nakhchivan	3	37	Gara gozal	3
12	Shahtakhti	3	25	Sharabi	3			
13	Zarafshan	4	26	Agh kishmish	3			

Since the Absheron Scientific-Research Base is located in the Absheron Peninsula, where the climate is hot and dry, downy mildew symptoms

are typically observed in the spring and early summer. However, its development halts after this period.

Table 3

The results of the phytopathological evaluations of downy mildew infections are as follows

Infection rates	Resistance score	Downy mildew	
		Leaf	Cluster
Highly resistant	1-1,5	-	-
Resistant	2-2,5	-	-
Tolerant	3-3,5	24	24
Unstable	4-4,5	13	13
Very unstable	5	-	-
Sum.	-	37	37

As shown in the table, the phytopathological evaluation of downy mildew disease (on leaves and clusters) was conducted under natural conditions. The evaluation of the clusters revealed that 13 varieties were classified as tolerant,

while 24 varieties were considered susceptible. No highly resistant, resistant, or highly susceptible varieties were found among the samples taken.



Figure 1. A leaf infected with the *Plasmopara viticola* Berk. & Berl. & de Toni. pathogen.

The absence of varieties showing highly susceptible reactions to major fungal diseases among the studied grape varieties can be explained by the fact that the Absheron Peninsula did not provide favorable conditions for the development and spread of the mentioned pathogens. In other words, there was a lack of sufficient humidity for the development and

dissemination of the pathogens. This is crucial because the growth and spread of these fungi require a certain level of relative humidity.

Cluster Analysis: The cluster analysis was conducted using the UPGMA method with the Euclidean distance index, as implemented in the PAST statistical software package (Figure 2).



Figure 2. Dendrogram constructed based on Euclidean distance.

Cluster analysis is a widely recognized method for uncovering the similarities and differences among genotypes. In our study, the genotypes formed two main clusters based on the traits we evaluated. Therefore, the dendrogram will be divided into these two clusters for

further analysis. As mentioned previously, we can visually observe that the evaluated grape genotypes have grouped into two distinct categories based on their infection rates

In the first cluster, 13 varieties were rated as tolerant with scores of 3-3.5, while in the

second cluster, 24 varieties were rated as susceptible with scores of 4-4.5. The tolerant grape varieties can be used in selection work to develop grape varieties resistant to the pathogen.

Conclusion

As shown in the table, a phytopathological evaluation of the downy mildew disease (on leaves and clusters) was conducted under natural conditions. Based on the evaluation of the clusters, 13 varieties were classified as tolerant, while 24 varieties were considered susceptible. No highly resistant, resistant, or

highly susceptible varieties were found among the samples.

The absence of varieties exhibiting highly susceptible reactions to major fungal diseases can be explained by the fact that the Absheron Peninsula did not provide favorable conditions for the development and spread of the pathogen. In other words, there was insufficient humidity for the development and dissemination of the pathogens. This is because the growth and spread of these fungi require a certain level of relative humidity.

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EVALUATION OF GENETIC DIVERSITY WITHIN THE GENE POOL OF POLONICUM WHEAT (*TRITICUM POLONICUM* L.) IN AZERBAIJAN

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Abstract. *The manuscript presents the results of an investigation into the morphometric and agronomic traits of new *T. polonicum* accessions from Azerbaijan, selected in hybrid and breeding nurseries at the Terter Research Station of the Azerbaijan Research Institute of Crop Husbandry. The study, which involved 164 *T. polonicum* accessions deposited in the National Gene Bank, revealed significant variability in growth habit, earing time, plant height, lodging, disease resistance, spike shape, and density, indicating a significant intraspecific polymorphism. The majority of the genotypes exhibited stability in their morphobiological characteristics, while some demonstrated new forms and varieties due to a resurgence of “open” flowering. Most of the *T. polonicum* genotypes were found to be resistant to lodging and diseases. The selected accessions are proposed for use as raw material in the development of low- and medium-height, high-yielding durum wheat varieties with excellent grain quality and resistance to diseases.*

Keywords: *T. polonicum* L.; subsp. *polonicum*; convar. *polonicum*; convar. *compactum*; subsp. *abyssinicum*; morphobiological traits; diversity.

Introduction

It is well known that the intraspecific genetic potential of both bread and durum wheat has been exhausted in terms of resistance to abiotic and biotic stress factors, as well as economically valuable traits. Rare wheat species that are genetically close and once occupied different geographic areas possess significant potential for enriching the intraspecific polymorphism of wheat. By involving these rare species and distant spontaneous hybrids in interspecific hybridization, it is possible to enrich bread and durum wheat with new genes and gene blocks that determine promising traits and provide transgression. Through hybridization followed by selection, newly developed varieties can achieve increased yield, grain quality, and resistance to environmental stress factors (11–12).

Polonicum wheat (*Triticum polonicum* L.) is

a rare hulled species of the genus *Triticum*. As suggested by Percival (19), the first description of this species (*Triticum speciosum grano longo*) was based on material from the Botanical Garden in Stuttgart. Under the name *T. polonicum*, this species was first mentioned in the catalogs and herbariums of European botanical gardens in the second half of the 17th century. Although this name is misleading (as it is not cultivated in Poland), it was adopted by C. Linnaeus (13).

Long-term observations show that in non-isolated, mixed plantings of tetra- and hexaploid species, the frequency and diversity of spontaneous hybrids increase. With targeted individual selection, the gene pool of any species can be enriched with new varieties and forms in a short period.

A fluorescent *in situ* hybridization (FISH) analysis was performed on the chromosomes

of 20 *T. polonicum* accessions using various repetitive sequences from the BAC library of the bread wheat cultivar Chinese Spring. Chromosomal patterns were compared with other tetraploid species of the *Triticum* genus ($2n = 4x = 28$, AABB): *T. durum*, *T. dicoccum*, and *T. turanicum*. Among the six DNA probes tested, the combination of RTA-86, RTA-535, and PTA-713 was the most informative. The RTA-k374 probe, which is similar to the 28S rDNA sequence, enabled differentiation based on signal size and position, as well as the detection of rDNA locus elimination. Polymorphism in signal distribution was observed on chromosomes 2A, 2B, 3B, 5B, 6A, and 7B. The telomeric region of the short arm of chromosome 6B showed the highest polymorphism (15).

Phenotypic research is the first approximation, which must be followed by genetic investigation (2). Therefore, the collection and refinement of the genetic potential of morphometric and agronomic traits, based on the study of intraspecific polymorphism at various levels and using different methods, as well as the creation of trait collections, breeding materials, genetic sources, and donors, remains both relevant and promising.

Materials and Methods

In 2011, ten initial founder forms of *Triticum polonicum* (polonicum-type wheat) were selected from hybrid and breeding nurseries of the Terter Regional Experimental Station (RES), along with other intra- and interspecific hybrids. These forms were also identified within hybrid combinations between durum and bread wheat. In subsequent years (2012–2025), under the agro-climatic conditions of the Absheron region, stable *T. polonicum* accessions were isolated from polonicum-type lines as a result of segregation and “secondary flowering.”

The collected material was analyzed using identification guides from the Vavilov All-Russian Institute of Plant Genetic Resources (VIR) (4–5), and subspecies and botanical varieties were determined. Phenological observations and evaluations were carried out using widely accepted methods (6; 8). The growth type was determined in spring at the end of the tillering

phase, based on the bush shape, using a 9-point scale (10).

Results and Discussion

Goy gol (1955) identified the region of Western Asia as the center of origin for *Triticum polonicum*, suggesting its derivation from *T. durum*. Vavilov (1931), Flaksberger (13), and others proposed a polyphyletic origin of *T. polonicum* from *T. durum* (cited in “Cultivated Flora of the USSR, Vol. 1, Wheat, 1979”). Based on a range of traits, *T. polonicum* corresponds to the species it coexists with in cultivation and mirrors their ecological and geographical differentiation. *T. polonicum* is divided into two subspecies: subsp. *abyssinicum* (an admixture found in *T. aethiopicum* Vav.) and subsp. *polonicum* (found within the range of *T. durum*). Subsp. *polonicum* (= *T. polonicum* subsp. *mediterraneum* Vav., 1931) is further divided into two convarietal groups: convar. *polonicum* and convar. *compactum* (4).

Polish wheat (*T. polonicum*) is a very rarely encountered species. In the Central Tien Shan region, the variety var. *levissimum* was discovered. These forms are of practical interest for breeding as sources of large grain size and vitreous kernels (3). It is presumed that *T. petropavlovskyi* arose from hybridization between *T. aestivum* and *T. polonicum*, followed by intensive selection (17).

In wheat fields of Azerbaijan, only the varieties v. *levissimum* and v. *pseudolevissimum* have been found. Previously, in crosses involving *T. turgidum*, a branched-ear form of *T. polonicum* was obtained. Later, Yakubtsiner classified it as a distinct variety (v. *mustafaevii* Jakubz., 1949) (9).

Over a relatively short period (2012–2025), twenty *T. polonicum* varieties have been identified, arising from morphogenesis and exhibiting significant variation in plant height, stem thickness, presence or absence of awns, awn coloration, ear coloration, shape and density, grain color and morphology, and other traits. Genotypes have been observed with common, fan-shaped, pyramidal, narrow, long, short, and branched ears. Branched ears are more frequently observed in favorable growing seasons. Seasonal conditions and sparse

planting promote the occurrence of branching (11–12). True branched-ear genotypes tend to be late-maturing. In some genotypes, anthocyanin pigmentation appears during the tillering-to-booting phases, while chlorotic yellowing occurs during heading and flowering.

Dwarf and semi-dwarf *T. polonicum* lines may be used to reduce plant height in durum wheat varieties. The semi-dwarf line *T. polonicum* IC12196 is an alternative source of the semi-dwarfing gene at the *RHT-B1* locus and may be valuable for developing short-stemmed durum wheat cultivars (22).

As a result of the study, 164 stable *T. polonicum* accessions belonging to 15 distinct

varieties were selected and deposited in the National Genebank. Most accessions belong to the varieties var. *chrysospermum*, var. *pseudolevissimum*, var. *skalasubovii*, var. *pseudochrysospermum*, var. *pissarevii*, var. *rufescens*, var. *pseudocaryopsirubrum*, var. *polonicum*, var. *rubrosemineum*, var. *caryopsirubrum*, var. *heydelbergi*, var. *abyssinicum*, and var. *levissimum* (represented by a single accession). Additionally, three new varieties were identified (v. *pseudorubrosemineum* var. *nova* and var. *azerpseudocaryopsirubrum* var. *nova*), which belong to *T. polonicum* subsp. *abyssinicum* (Table 1, Figures 1, 2).

Table 1

New botanical varieties of *Triticum polonicum* in Azerbaijan

Subsp. abyssinicum	Characteristic traits and properties
v. <i>abyssinicum</i>	Awned, glume scales are white, non-hairy, awns and grain are white
v. <i>pseudoabyssinicum</i> var. <i>nova</i>	Awned, glume scales are white, non-hairy, awns are black, grain is white.
v. <i>rubrosemineum</i>	Awned, glume scales are white, non-hairy, awns are white, grain is red.
v. <i>pseudorubrosemineum</i> var. <i>nova</i>	Awned, glume scales are white, non-hairy, awns are black, grain is red.
v. <i>azerpseudocaryopsirubrum</i> var. <i>nova</i>	The spike is dense, awned, with white, non-hairy glumes, black awns, and red grains.

Compared to bread wheat, *Triticum polonicum* contains significantly higher levels of sulfur, magnesium, and potassium, as well as zinc, iron, copper, and molybdenum, and significantly lower levels of aluminum and strontium. Polish wheat can be used as a valuable genetic material for the selection of new wheat varieties characterized by high nutritional value and resistance to fusarium disease (15).

The elongated outer floral glume is characteristic of *T. polonicum*, *T. ispahanicum*, and *T. petropavlovskyi*. However, in *T. ispahanicum*, there is no association between this trait and the parchment-like consistency of the glume. It is possible that the factors responsible for glume elongation in *T. polonicum* and *T. ispahanicum* are different. In *T. petropavlovskyi*, the action of factor P is somewhat suppressed, possibly due to the presence of factor Q and the D genome. The most pronounced expression of factor P is

characteristic of *T. polonicum* (4). This factor (P1) is localized in the long arm of chromosome 7A in *T. polonicum* (19), and in the long arm of chromosome 7B in *T. ispahanicum* (20). The P gene in *T. petropavlovskyi*, like in *T. polonicum*, is localized in the long arm of chromosome 7A and is allelic to it (21). The chromosome 7A of the monosomic line of the Saratov 29 variety is marked by the P genome (Eg1), which determines the presence of elongated glumes in *T. polonicum* and *T. petropavlovskyi* species (7).

The new accessions vary in spike density and awnlessness: spikes are awnless with short and regular awns; spikes are short, medium-length, and long; spikes are loose, medium-dense, and ultradense; spikes are fan-shaped. In favorable years, samples with true branched spikes were identified (Figures 1, 2).



Figure 1. Dwarf genotypes of *T. polonicum* with true branching

Among all the years of study, the years 2015–2016 showed potentially high growth rates: the plant height was 10–20 cm higher compared to other years (11–12). The new samples, transferred to the Gene Bank, also showed a sharp variation in plant height: dwarf samples were absent, with the minimum height being 70.0

cm, the maximum height being 177.0 cm, and the average height being 122.0 cm.

For plant height, the *T. polonicum* samples are ranked as follows: 70–85 cm, 86–100 cm, 101–120 cm, 121–140 cm, and over 140 cm. For samples belonging to subsp. *abyssinicum*, the plant height ranged between 70–95 cm.



Figure 2. New genotypes of *T. polonicum* from Azerbaijan

Most of the accessions from the VIR global collection exhibit a spring growth habit (4). The new accessions transferred to the Gene Bank differ in terms of their growth habit: nearly half of the accessions (47.5%) have a winter growth habit (score 9), with 24.6% being true winter types (score 9+). Biologically, no spring habit accessions were found. We believe that the predominance of winter types in the new accessions is linked to the fact that the parent pairs -modern varieties - mostly exhibit winter and semi-winter growth habits.

Under favorable meteorological conditions,

the heading dates of the new accessions accelerated, and they showed significant variation in this trait (April 1st to May 15th). More than half of the accessions headed in April, while 47.5% headed in the first decade of May. Among the genotypes with early heading, especially the semi-dwarf forms, a phenomenon of incomplete fertilization was observed due to low temperatures during the flowering phase, which disrupted the fertilization process. True winter types mostly headed later (Table 2).

Table 2

Agrobiological Characteristics of New Accessions of *T. polonicum* L.

Botanical variety	Bush type, score	Earing, date	Plant height, cm	Spike					1000 grain weight, gr
				Length, cm	Number of spikelets, pcs.	D — density, pcs.	Number of grains, pcs.	Grain weight, gr	
<i>v. chrysospermum</i>	9	01.V	123.0	13.9	18.8	13.5	52.7	2.0	37.6
<i>v. chrysospermum</i>	7	05.V	115.0	14.8	19.6	13.2	44.0	1.8	40.2
<i>v. rufescens</i>	9+	23.IV	110.0	12.7	19.5	15.4	41.4	2.8	68.4
<i>v. pseudolevissimum</i>	7	15.IV	95.0	14.1	21.2	15.0	38.5	2.0	50.0
<i>v. chrysospermum</i>	9	23.IV	132.0	12.7	17.1	13.5	42.5	2.4	56.9
<i>v. pseudorubrosemineum</i> var. <i>nova</i>	5	13.IV	70.0	11.1	14.8	13.3	23.6	0.8	34.7
<i>v. pseudorubrosemineum</i> var. <i>nova</i>	5	12.IV	72.0	10.6	13.9	13.1	24.1	0.8	33.4
<i>v. rubrosemineum</i>	3	20.IV	82.0	12.4	17.9	14.4	50.0	1.8	35.4
<i>v. chrysospermum</i>	5	19.IV	90.0	11.1	16.1	14.5	49.1	1.7	34.2
<i>v. pseudolevissimum</i>	7	24.IV	100.0	13.7	15.4	11.2	14.8	1.0	64.1
<i>v. skalasubovii</i>	9+	25.IV	112.0	14.5	19.2	13.2	36.6	2.4	64.8
<i>v. skalasubovii</i>	9+	25.IV	121.0	14.9	19.8	13.3	23.7	1.8	75.5
<i>v. chrysospermum</i>	9+	23.IV	74.5	16.2	19.3	11.9	28.8	1.9	60.0
<i>v. pissarevii</i>	7	29.IV	128.0	15.3	21.6	14.1	49.9	2.4	50.0
<i>v. pissarevii</i>	9+	05.V	110.0	13.0	24.0	18.5	60.0	2.3	30.0
<i>v. pissarevii</i>	9	05.V	110.0	13.3	25.9	19.5	53.0	2.2	40.0
<i>v. caryopsirubrum</i>	9	04.V	142.0	11.7	21.7	18.5	49.7	2.4	40.0
<i>v. pissarevii</i>	7	26.IV	137.0	12.5	19.4	15.5	41.5	2.6	60.0
<i>v. skalasubovii</i>	9	02.V	155.0	14.3	22.2	15.5	50.7	2.5	40.0
<i>v. skalasubovii</i>	7	27.IV	120.0	12.9	18.4	14.3	24.6	1.5	60.4
<i>v. chrysospermum</i>	9+	05.V	145.0	12.4	22.0	17.7	42.1	2.3	53.9
<i>v. chrysospermum</i>	9+	03.V	153.0	14.8	24.0	16.2	34.6	1.8	52.7
<i>v. skalasubovii</i>	9	06.V	152.0	13.8	22.4	16.2	39.3	2.0	50.6

<i>v. rufescens</i>	9	02.V	163.0	15.4	22.5	14.6	45.8	2.4	51.4
<i>v. ps.chrysospermum</i>	9	05.V	158.0	13.9	21.8	15.7	41.3	2.4	57.6
<i>v. ps. caryopsirubrum</i>	3	19.IV	100.0	13.0	20.6	15.8	45.0	1.6	34.9
<i>v. azerpseudocaryopsirubrum</i> var. <i>nova</i>	9+	12.V	84.0	13.8	21.3	15.4	20.7	0.5	30,0
<i>v. polonicum</i>	8	02.V	129.0	14.5	22.6	15.6	49.1	2.4	48.7
<i>v. heydelbergi</i>	8	02.V	156.0	17.5	22.5	12.9	28.1	1.5	54.1
<i>v. pseudolevissimum</i>	9+	03.V	147.0	14.0	18.4	13.1	33.4	1.7	50.0
<i>v. pseudochrysospermum</i>	9+	19.IV	133.0	14.4	19.8	13.8	42.0	2.0	46.9
<i>v. abyssinicum</i> , <i>rubrosemineum</i>	7	01.V	94.0	13.4	22.7	16.9	35.6	1.7	46.9
<i>v. pseudocaryopsirubrum</i>	9	04.V	95.0	12.7	24.2	19.1	44.6	1.8	39.2
<i>v. chrysospermum</i>	9+	04.V	150.0	14.1	20.1	14.3	46.0	2.3	50.9
<i>v. pissarevii</i>	9	05.V	90.0	12.7	23.3	18.3	40.2	1.9	47.0
<i>v. chrysospermum</i>	7	25.IV	139.0	14.3	18.1	12.7	41.4	1.7	40.6
<i>v. polonicum</i>	9	02.V	140.0	12.3	20.9	17.0	30.7	1.4	44.0

No significant correlation was found between the timing of heading, systematic affiliation, and plant height of the accessions. Accessions with early and late heading times included low, medium, and tall genotypes, belonging to subsp. *abyssinicum*, convar. *polonicum*, and convar. *compactum*. The fast-growing forms had a spring-winter, semi-winter, and winter-spring growth habit (Table 3).

The grain shape of the new accessions was primarily elongated (7–12 cm), although low-growing accessions exhibited genotypes with almost oval-shaped grains. In favorable years, most accessions had elongated grain shapes and a vitreous consistency. The new *T. polonicum* accessions also differed in their resistance to diseases. They were susceptible to powdery mildew, but most genotypes showed high resistance to yellow and brown rusts.

The new *T. polonicum* accessions also varied in terms of yield structure components. Analysis of stable accessions showed that the variability in the length (max – 17.5 cm, min – 9.4 cm, average – 13.1 cm) and density (max – 25.9 spikes, min – 13.9 spikes, average – 20.1 spikes) of the ears was wide. For one-third of the samples, the ear length exceeded 13.1 cm, and the number of spikes was more than 20.1 spikes. The number of grains per ear (max – 60.0, min

– 8.2, average – 37.9), grain mass per ear (max – 2.83, min – 0.32, average – 1.80), and the mass of 1000 grains (max – 75.5, min – 26.1, average – 47.8) also exhibited polymorphism. For 25% of the samples, the number of grains per ear was 39.5 or more, and for 9% it was 25.0 or fewer. Despite the relatively large ear, some accessions exhibited low grain filling. Some accessions, especially rare varieties, exhibited spikelet sterility, while others showed large grain size – one-third of the genotypes had a 1000-grain mass of 50.0 g or more.

Conclusions

The study of 61 new accessions of *T. polonicum*, received in recent years at the National Genebank, revealed that there is a very high variability in terms of life form, heading time, plant height, resistance to lodging and diseases, as well as the shape, density, and grain filling of the ear. A wide intra-species polymorphism was observed for all indicators. Most of the *T. polonicum* accessions were found to be resistant to lodging and diseases. The new accessions, when involved in breeding, can be used as initial material for new introgressive lines to create high-yielding hard wheat varieties with high grain quality and disease resistance. Dwarf and semi-dwarf forms can be used as a genetic source of reduced plant height.

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COMPARATIVE ECOLOGICAL ANATOMICAL STUDY OF THE STRUCTURAL ADAPTATION OF THE MEDICINALLY IMPORTANT PLANT *SALVIA NEMOROSA* L. UNDER IN SITU AND EX SITU CONDITIONS

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Abstract. *The main objective of the research is to conduct a comparative ecological anatomical analysis of the medicinally important species Salvia nemorosa, which belongs to the Lamiaceae family and is distributed in the territory of the Republic of Azerbaijan under both in situ and ex situ conditions. Comparative anatomical analyses were carried out using anatomical, microscopic, histochemical, and biometric methods to determine how anatomical variability may be reflected in the ecotypes of the same species and to explore their environmental adaptation capabilities. Anatomical sections prepared from the studied species were subjected to histological staining using reagents, and permanent slides were then prepared from these samples. Microscopic investigations revealed that in the leaves of S. nemorosa, the functional activity of tectorial and capitate trichomes was identified in the in situ sample, in contrast to the ex situ sample. Granular inclusions were observed in the libriform fibers of the root of the S. nemorosa specimen grown under in situ conditions. A tetrarch type of protoxylem structure was observed in the root of the in situ specimen, while a hexarch type was formed in the ex situ specimen. The identified ecotopic structural adaptations represent an advancement in the field of ecological anatomy and hold significant scientific and practical importance.*

Keywords: *tectorial trichome, capitate trichome, eccentric central cylinder, epistome, granular inclusion structure, parenchymatic excretion*

Introduction

Salvia nemorosa is a plant species belonging to the genus *Salvia* of the family Lamiaceae, naturally distributed in the Republic of Azerbaijan (Fig. 1). It is primarily found on mountain slopes, forest edges, meadows, and similar habitats (Gurbanov, 2024). This perennial species has a quadrangular stem structure and is relatively rigid. The rigidity and shape of the stem are attributed to the collenchyma fibers, which run along the four sides of the stem and can be observed in cross-section, providing mechanical support (Bercu et al., 2012; Aliyeva & Salimov, 2021). As the stem grows vertically, it

begins to branch. The branches are arranged straight, with generative organs forming at their ends. The leaves of the plant are lanceolate or ovate-lanceolate, with dentate or undulating margins. They are arranged in an opposite-decussate manner along the stem. The leaf morphology is rugose and covered with dense trichomes (Bagheri et al., 2016a).

The chemical composition of *S. nemorosa* primarily consists of essential oils and terpenoids, phenolic compounds and flavonoids, diterpenoids and triterpenoids, polysaccharides, and other components (Chizzola, 2012; Mahdieh et al., 2018). Among the essential oils

and terpenoids, cineole is aromatic, borneol has antiseptic properties, caryophyllene is antioxidant and antimicrobial, camphene is antibacterial and antifungal, and pinene and linalool exhibit sedative effects. Phenolic compounds such as rosmarinic and caffeic acids have strong antioxidant and antimicrobial properties. Flavonoids such as apigenin, luteolin, and quercetin possess antioxidant properties. Carnose acid has neuroprotective properties, while ursolic acid is cell-protective, antimicrobial, and anticancerous, belonging to the diterpenoid and triterpenoid groups. Mucopolysaccharides act as immunostimulants. These components confirm the phytotherapeutic properties of the plant (Ibadullayeva, 2024).

Considering the potential use of *S. nemorosa* in folk medicine and modern medicine for therapeutic purposes, its inclusion in ecological-anatomical research is a relevant issue. Furthermore, current studies indicate that investigating species under in situ and ex situ conditions is of great importance for determining their adaptation capabilities and preserving biodiversity (Sərdarova, 2018; Khamraeva et al., 2021; Sun et al., 2022; Sardarova 2024a, 2024b, 2024c). In terms of resistance to climate variability, the study of anatomical and physiological adaptation mechanisms of *S. nemorosa* at the ecotope level is currently a highly relevant research topic discussed on international platforms.



Figure 1. A: *Salvia nemorosa*, Shusha city (in situ); B: *Salvia nemorosa*, Ganja city (ex situ)

Materials and Methods

Collection of Material. *Salvia nemorosa* was collected from the city of Shusha in May 2021 and initially cultivated ex situ in container culture in the Bala Baghman area of Ganja city. After one year, it was transplanted into open soil conditions, where it developed under the region's normal natural conditions without any artificial intervention.

Material Processing. In 2023, samples from both in situ and ex situ plants were collected and placed in fixatives for analytical purposes. Subsequently, anatomical sections were prepared from the fixed material using a microtome (RADICAL, RMT-5, India). During this process, paraffin (BW Blended Waxes, Inc. US) was used as an auxiliary medium both for infiltration and the sectioning process (Erişen et al., 2024). The

thickness of the sections was calibrated using the special micrometric adjustment screw on the microtome, and measurements were taken in microns recorded (Fig. 2). The thickness of the sections obtained using the microtome was determined to be within the range of 7, 8, and 9 μm through micrometric adjustment. After obtaining the microtome sections, histochemical methods were applied, and differential staining was conducted using specific reagents. Special stains used during this process included safranin O (KimyaLab, Turkey), fast green, Sudan III, toluidine blue, phloroglucinol-HCl, and methylene blue (INOVATING SCIENCE, US). Additionally, various chemical reagents such as xylene, carboxylol, and ethylene (Mir Nauki, Russia) were widely used. The staining process, applied for the selective coloring of tissue components, was carried out step by step using the decolorization method (Pradhan Mitra, Loqué, 2014;

Moyo et al., 2015; Bozdağ et al., 2016; Da Silva et al., 2020; Engin et al., 2024). The consecutive use of various histological staining techniques allowed for a more precise clarification of the comparative ecological anatomical structure components of *S. nemorosa* in both ex situ and in situ conditions. For the preparation of permanent slides from the stained sections, Canada balsam (INOVATING SCIENCE, US) was used. A drop of balsam was placed onto the section positioned on a microscope slide (AmScope, USA), and then a cover slip was mounted on top. The prepared slides were placed in a special incubator device with a stable temperature (20–25°C) for complete drying of the Canada balsam, and were kept there until fully dried. Permanent preparations from the plant's transverse sections were then subjected to microscopic analysis.



Figure 2 . Preparation of permanent slides (histology staining stage).

Microscopic Investigations. The research was conducted using the “Carl Zeiss, Axio Imager A2” microscope (ZEISS, Germany), equipped with a LED light source and special objectives (5 $\times$, 10 $\times$, 20 $\times$, 40 $\times$, 100 $\times$) that minimize aberration (Fig. 3). Additionally, the LCD Digital Microscope NLCD-307B model (Wincom Company Ltd., China) was used (Fig. 4 A, B). During the research, the LCD Digital Microscope NLCD-307B was utilized to monitor the quality of the transverse sections obtained from the plant samples and the effectiveness of the histological staining until the preparation of permanent slides. Final analyses on the prepared slides, photomicrograph acquisition, and the obtaining of

statistical measurements were performed using the Carl Zeiss, Axio Imager A2 model. Observations at 100 $\times$ magnification were carried out using immersion oil (RMY, US). The use of the immersion medium enhanced optical resolution, improving the accuracy and contrast of the microscopic images of the studied samples. Stereoscopic microscopes were also used to perform macroscopic analysis of the samples during the study (Stereo microscope Zeiss Stemi508 (ZEISS, Germany), Stereo YK-SM067B2 (Wincom Company Ltd., China)) (Fig. 4 C, D).

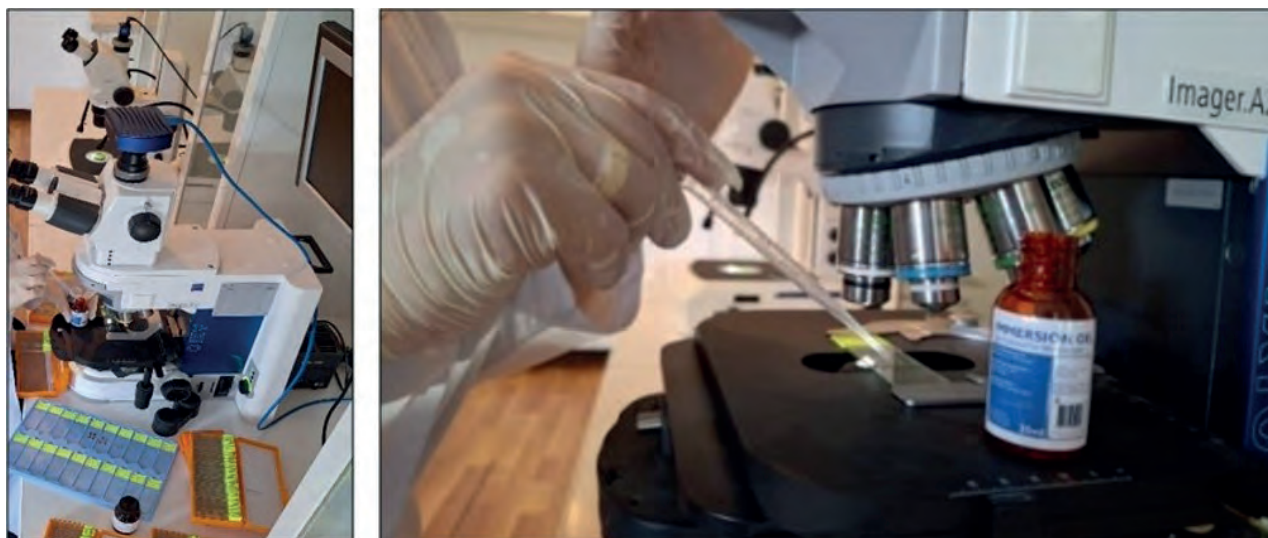


Figure 3. Carl Zeiss, While working with the Axio imager A2 optical microscope model.

Biometric Methods. During the analyses, eyepiece and stage micrometers (MUHVA, China) were used to verify the accuracy of the micrometric indicators obtained automatically through the microscope. First, the eyepiece micrometer was calibrated using the stage micrometer, and then the measurements of the observed objects were calculated based on the

scales on the micrometers. Additionally, a digital micrometer (Jiavarry, China) was used to record the macroscopic dimensions of the organs from which the sections were taken. The obtained measurement data were appropriately placed on the photomicrographs (Jambor et al., 2021).



Figure 4. Optical and stereoscopic microscopes used. A, B: LCD Dijital Mikroskop NLCD-307B; C: Steroscope Zeiss Stemi508; D: Stereo YK-SM067B2.

Herbarium Preparation. The systematically prepared herbarium specimens from the medicinally valuable *S. nemorosa* plant not only provide a basis for the in-depth analysis of the species' ecology and anatomy but also serve as reference material to assess its potential in pharmacognosy and phytotherapy (Uma & Düzenli, 2012). Herbarium materials prepared from both comparatively studied samples of

the *S. nemorosa* species are included in the herbarium collection of the Department of Biology named after Academician Valida Tutayuyq at the Azerbaijan State Agricultural University. They are maintained as a systematically organized botanical collection and are open for scientific research, educational, and reference purposes.

Statistical Method. In this study, samples of the *S. nemorosa* species collected from two

regions of the Republic of Azerbaijan with different ecological characteristics were statistically analyzed based on various parameters. From the populations of the same species in both regions, 8–12 individual plants were selected, and samples from the vegetative organs of each plant were taken for the study. For each organ, 10–15 transverse sections were prepared and subjected to anatomical analysis. During the microscopic analyses, various parameters were measured. All measurements were analyzed using the RStudio program (version 2023.09.1, R Foundation for Statistical Computing, Austria). For parameters with confirmed normal distribution, a two-sample ANOVA (analysis of variance) test was applied, while for those without normal distribution, the Mann–Whitney U test was used. All results were presented as mean $\pm$ standard deviation (SD), and statistical differences were considered significant at the $P < 0.05$ level.

Results

Flower stem. As observed in the transverse sections of flower stem from both in situ and ex situ conditions of *S. nemorosa*, they possess four prominent angular structures (Fig. 5 A, B). The central region, composed of pith parenchyma, is predominantly surrounded by well-developed vascular bundles extending toward the corners (Polat, 2004) (Fig. 5 A1, B1). In the in situ specimen, the pith contains large isodiametric parenchyma cells in the central

area, while the cells in the perimedullary region appear smaller. In contrast, the transverse section of the ex situ specimen reveals numerous aerenchyma spaces in the center of the pith (Fig. 5 A2, B2). The vascular bundles surrounding the pith are more developed in the in situ specimen. Here, the xylem tissue is thicker, containing more vessel elements and, unlike in the ex situ specimen, also consisting of libriform fibers. In the ex situ specimen, phloem tissue forms continuously along the entire cambial belt. The smaller vascular bundles in the ex situ specimen are separated by medullary rays, with phloem tissue developing only within the bundles (Fig. 5 A4, B4). In the in situ specimen, sclerenchyma tissue has formed outward from the vascular bundles toward the cortex. The epidermis of the flower stem is covered with tectorial and capitate trichomes, which serve a protective function (Viktorov et al., 2017). Microscopic analyses revealed that metabolic processes were more intense in capitate trichomes compared to tectorial trichomes. The in situ sample contained both types of trichomes, with tectorial trichomes being longer than those in the ex situ sample. In the corner regions of the flower stem, collenchyma tissue has formed on the inner side of the epidermis. In the in situ specimen, this tissue consists of a greater number of cells, has a thicker wall, and is more densely packed (Table 1).

Table 1:

Quantitative characteristic of the flower stems of *Salvia nemorosa*, μm

Indicators	<i>In situ</i> (Mean $\pm$ SD)	<i>Ex situ</i> (Mean $\pm$ SD)
The height of the epidermis cells	10,64 $\pm$ 1,63	19,16 $\pm$ 2,72
Radial thickness of the collenchyma tissue	53,24 $\pm$ 3,81	51,24 $\pm$ 3,17
The thickness of the cortex	51,11 $\pm$ 4,08	129,51 $\pm$ 8,45
Diameter of the cortical parenchyma cells	17,03 $\pm$ 3,29	29,81 $\pm$ 2,86
Diameter of the pith parenchyma cells	39,40 $\pm$ 4,63	34,07 $\pm$ 3,48
Diameter of the xylem vessel	12,77 $\pm$ 1,57	12,37 $\pm$ 1,14

Note - ANOVA and Mann–Whitney U tests were applied for statistical analysis ($P < 0.05$)

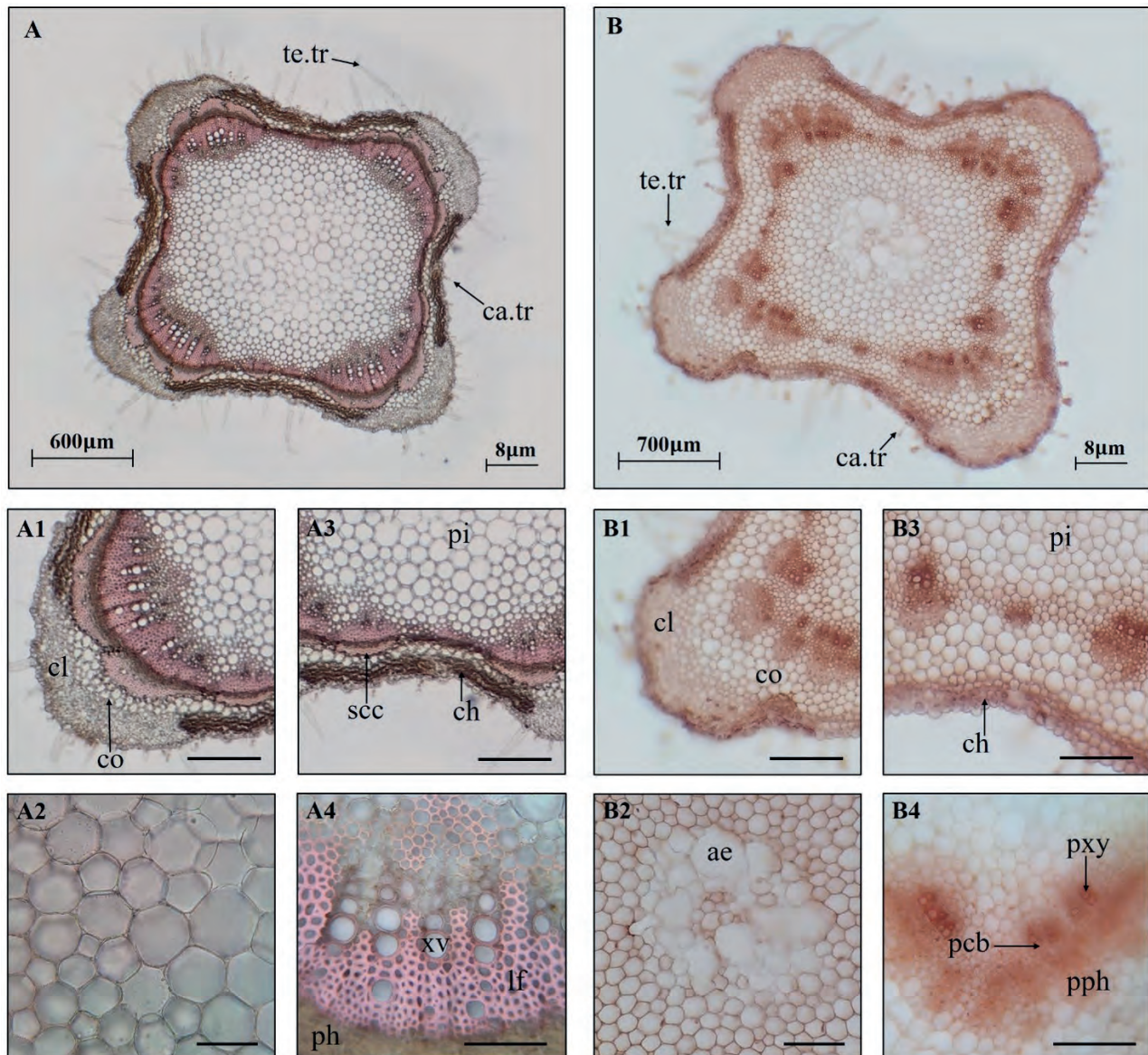


Figure 5. *Salvia nemorosa*. Flower stem. A (in situ), B (ex situ): General view (10x16); A1, B1: Ridges (40x); A2, B2: Pith (40x); A3, B3: Inter-bundle region (40x); A4, B4: Vascular bundle (60x); te.tr-tectorial trichome; ca.tr-capitate trichome; ch-chlorenchyma; cl-collenchyma; co-cortex; pi-pith; scc-sclerenchyma; pxy-protaxylem; pph-protophloem; pcb-procambium; xv-xylem vessels; lf-libriform fibres; ph-phloem. (scale bar: A1, B1 – 100µm; A2, B2 – 60µm; A3-4, B3-4 – 100µm)

In the cortical region between the angular corners, chloroplast-containing parenchyma cells are observed in subepidermal areas. In the in situ specimen, these smaller cells form dense layers of four to five rows, accumulating more chloroplasts. In contrast, the ex situ specimen has only two to three layers of such tissue. Toward the pith, the large parenchyma cells of the cortex are positioned beyond the chloroplast-containing cells. This layer consists of one to two cell rows in the in situ specimen, while in the ex situ specimen, it comprises four to five

layers (Fig. 5 A3, B3). The cortical parenchyma progressively thickens toward the corners.

Leaf. The leaf of *S. nemorosa* has a dorso-ventral structure, with the region traversed by the midrib expanding ventrally. In the ex situ sample, this area is larger in size, and its parenchyma is composed of a greater number of cells. In contrast, in the in situ specimen, the parenchyma cells are smaller, and the tissue complex appears more compact (Fig. 6 A, B) (Table 2).

Table 2:

Quantitative characteristic of the leaves of <i>Salvia nemorosa</i> , μm		
Indicators	In situ (Mean $\pm$ SD)	Ex situ (Mean $\pm$ SD)
The height of the abaxial epidermis cells	26,85 $\pm$ 2,31	25,57 $\pm$ 1,03
Diameter of the parenchyma cells	54,98 $\pm$ 2,76	62,65 $\pm$ 3,32
The height of the central vascular bundle	281,07 $\pm$ 5,47	249,84 $\pm$ 7,59
Diameter of the xylem vessel	21,86 $\pm$ 2,64	20,46 $\pm$ 1,91

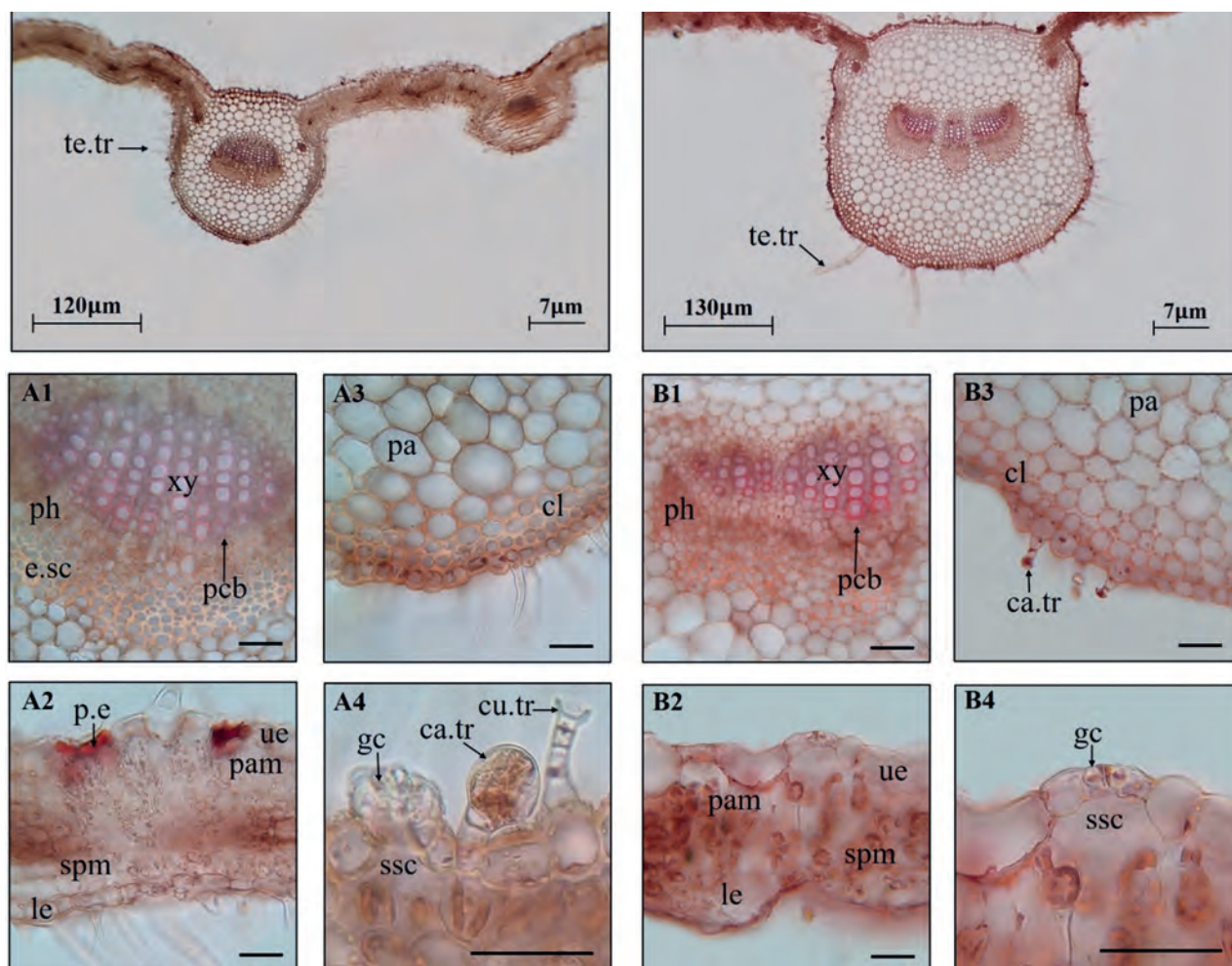


Figure 6. *Salvia nemorosa*. Leaf. A (in situ), B (ex situ): General view (4x16); A1, B1: Central bundle (40x); A2, B2: Mesophyll region (40x); A3, B3: Part of dorsal prominence (40x); A4, B4: Peripheral region (100x). ue-upper epidermis; le-lower epidermis; pa-parenchyma; pam-palisade mesophyll; spm-spongy mesophyll; cl-collenchyma; e.sc-early sclerenchyma; p.e-parenchymatic excretions; xy-xylem; ph-phloem; pcb-procambium; ssc-sub-stomatal cavity; gc-guard cell; ca.tr-capitate trichome; te.tr-tectorial trichome; cu.tr-cup-shaped trichome. (scale bar: A1-3, B1-3 – 50 μm ; A4, B4 – 40 μm)

In the in situ specimen, the main vascular bundle located at the center of the leaf contains a greater number of xylem elements. Thickening of the walls of the xylem vessels is more actively developed in comparison to the

ex situ sample. In the ex situ specimen, the central vascular system is divided into three distinct bundles by parenchymal rays. Within the vascular bundles, the procambium undergoes periclinal divisions to produce new phloem and

xylem elements (Rudik & Mulyan, 2013; Hardtke, 2023). In the in situ specimen, the primary sclerenchyma, which forms in the ventral region adjacent to the phloem, exhibits normal thickening of cell walls, whereas this feature is less developed in the ex situ specimen (Fig. 6 A1, B1). In the comparative analysis of the leaves of *S. nemorosa*, the visualization of brown-colored parenchymatic excretions localized in the palisade parenchyma of the mesophyll and the adaxial epidermis covering it was conducted using different magnification levels of the objective lenses (Fig. 6 A2, B2). Additionally, dark-colored constitutional substances accumulate in the cells of the abaxial epidermis in the expanded region of the leaf. The lower localization of these substances in the ex situ sample is associated with its presence in a stable ecological environment with minimal stress factors and ensured constant conditions (Sardarova, 2022b). The adaxial and abaxial epidermis of the leaf is covered with multicellular trichomes, including capitate trichomes with a distinct large head, short multicellular trichomes with a cup-shaped small head, and longer tectorial trichomes (Kahraman et al., 2015). The trichome density is higher in the in situ sample, contributing to adaptation to extreme environments (Sardarova, 2011; Mousavi et al., 2014; Kiseleva et al., 2016). In the ex situ sample, the formed tectorial trichomes were observed to be longer compared to those in the in situ sample. Microscopic analyses confirmed the presence of epistomatic structures in the adaxial epidermis of both in situ and ex situ specimens (Kahraman

et al., 2009) (Fig. 6 A4, B4). In the in situ specimen, a subepidermal collenchyma layer, composed of two to three cell rows, has formed in the ventrally expanded regions of the leaf. In contrast, this tissue is weakly developed in the ex situ specimen, appearing as a single-cell layer (Fig. 6 A3, B3). **Petiole.** The cr66oss-sectional analysis of the petiole of *S. nemorosa* revealed that the parenchyma tissue is more developed in the ex situ specimen. The vascular system at the center of the petiole is composed of two bundles in the in situ specimen, whereas in the ex situ specimen, it appears as three separate bundles. Additionally, two small-sized vascular bundles are observed at both lateral edges of the petiole (Fig. 7 A, B). In the in situ sample, vascular elements were strongly developed, and thickening of the walls of the xylem vessels proceeded more actively. The xylem, which contains a higher number of elements, exhibits a more organized structure compared to the ex situ specimen. The phloem cells in the vascular bundles of the in situ specimen are more numerous and densely arranged. The cell walls of the phloem fibers also show noticeable thickening. Furthermore, the mechanical cells surrounding the phloem have thicker walls in the in situ specimen than in the ex situ specimen. Some of these mechanical cells have undergone internal wall thickening, leading to the loss of cytoplasm and the formation of dead cells (Fig. 7 A3, B3). Unlike the central bundle, the lateral vascular bundles are larger in the ex situ specimen (Table 3).

Table 3

Quantitative characteristic of the petioles of *Salvia nemorosa*, μm

Indicators	In situ (Mean $\pm$ SD)	Ex situ (Mean $\pm$ SD)
The height of the epidermis cells	20,51 $\pm$ 1,03	18,84 $\pm$ 1,24
The thickness of the cell outer walls	3,41 $\pm$ 0,48	2,56 $\pm$ 0,38
Diameter of the parenchyma cells	86,53 $\pm$ 5,34	92,14 $\pm$ 6,08
The height of the central bundle	298,04 $\pm$ 8,26	259,59 $\pm$ 7,32
The height of the lateral bundle	132,89 $\pm$ 3,81	149,94 $\pm$ 4,47
Diameter of the xylem vessel	21,19 $\pm$ 2,37	25,18 $\pm$ 1,86

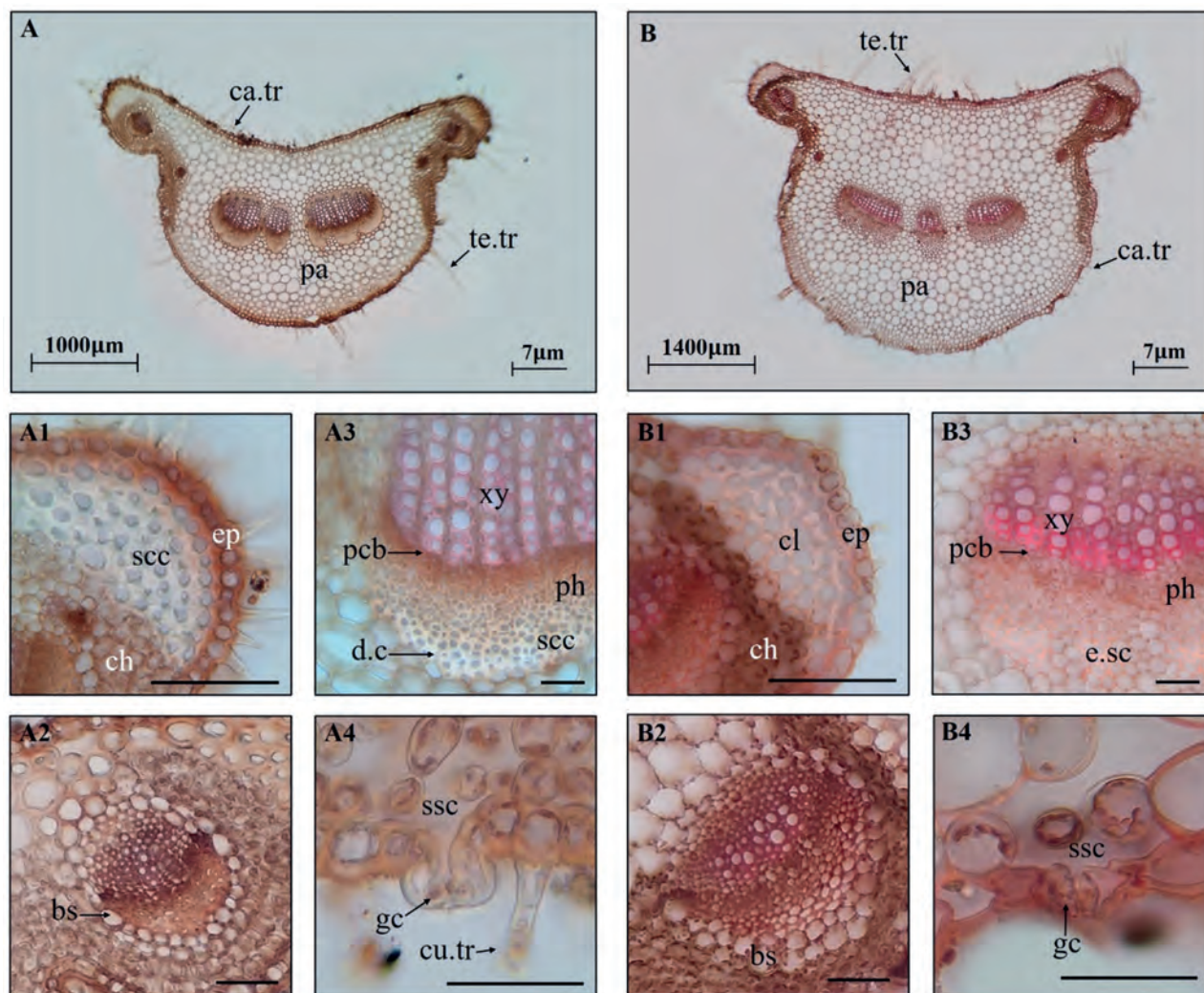


Figure 7. *Salvia nemorosa*. Petiole. A (in situ), B (ex situ): General view (4x16); A1, B1: Petiole wing (40x); A2, B2: Lateral collateral bundle (40x); A3, B3: Central bundle (40x); A4, B4: Stoma structure (100x). ep-epidermis; pa-parenchyma; bs-bundle sheat; ch-chlorenchyma; cl-collenchyma; e.sc-early sclerenchyma; scc-sclerenchyma; xy-xylem; ph-phloem; pcb-procambium; ca.tr-capitate trichome; te.tr-tectorial trichome; cu.tr-cup-shaped trichome; ssc-sub-stomatal cavity; gc-guard cell; d.c-dead cell. (scale bar: A1, B1 – 100µm; A2, B2 - 60µm; A3, B3 - 50µm; A4, B4 -60µm)

In the subepidermal layer of the petiole's outer region, the chloroplast-containing parenchyma is more actively developed. The small vascular bundles in contact with this chlorenchyma are separated from it by sheath cells (Fig. 7 A2, B2). At the ends of the petiole wings, angular collenchyma is present, while lacunar collenchyma develops in the lower subepidermal region (Kılıç M. & Kılıç F., 2022; Bagheri et al., 2016b). In the in situ specimen, collenchyma cells exhibit a higher degree of wall thickening, which is considered an adaptation mechanism to the harsh climatic conditions of the mountainous region where *S. nemorosa* naturally grows (Fig. 7 A1, B1). The epidermal

tissue, which serves as the petiole's protective covering, contains a small number of stomata distributed throughout its surface. In the in situ specimen, the stomata have an epistomatic structure, meaning they are raised above the epidermal surface. In contrast, in the ex situ specimen, the guard cells of the stomata are mostly at the same level as the epidermal cells (Fig. 7 A4, B4). In both in situ and ex situ specimens of *S. nemorosa*, a small accumulation of constitutional substances was observed in the epidermal cells. Microscopic analysis revealed that the surface of the petiole in the in situ sample was covered with densely formed, short trichomes and more sparsely distributed,

elongated, multicellular tectorial trichomes. The majority of the short trichomes consist of multicellular stalks and capitate heads positioned on top, which have a secretory function. Among them, glandular trichomes with a calyx-shaped or cup-shaped small head are also observed (Özkan & Soy, 2007; Kaya, 2024). The remaining portion was composed of small tectorial trichomes. On the surface of the ex situ sample, these trichomes were observed in significantly lower numbers.

Stem. The anatomical analysis of the cross-section of the ex situ *S. nemorosa* stem revealed that each of the four-angled stem corners is well-developed with collenchyma tissue. In the in situ specimen of *S. nemorosa*, the entire tissue complex retains a conservative

structure (Fig. 8 A, B). Each of the four corners contains a mechanical tissue composed of six to eight layers of highly sclerified and rigid cells. Using the modern digital Carl Zeiss Axio Imager A2 microscope with a 60x objective lens, it was determined through higher magnification imaging that in the in situ sample, the collenchyma located at the corners of the stem partially differentiated and underwent sclerenchymatization, which is considered an ecotypic indicator reflecting the transition of collenchyma to sclerenchyma in mechanical cells. In the in situ sample, densely arranged, few parenchyma cells were recorded. Conversely, in the ex situ specimen, the cortex is thicker and composed of larger cells (Table 4).

Table 4
Quantitative characteristic of the stems of *Salvia nemorosa*, μm

Indicators	In situ (Mean $\pm$ SD)	Ex situ (Mean $\pm$ SD)
The height of the epidermis cells	12,39 $\pm$ 1,46	25,17 $\pm$ 1,52
Radial thickness of the collenchyma tissue	74,76 $\pm$ 2,35	261,67 $\pm$ 4,51
The thickness of the cortex	130,83 $\pm$ 6,75	209,34 $\pm$ 5,88
Diameter of the cortical parenchyma cells	34,01 $\pm$ 2,75	55,98 $\pm$ 1,35
Diameter of the pith parenchyma cells	67,62 $\pm$ 3,51	73,45 $\pm$ 3,25
Diameter of the xylem vessel	18,68 $\pm$ 1,74	24,25 $\pm$ 1,49

The subepidermal layer, which contains chloroplast-rich parenchyma, is highly developed in the in situ specimen (Fig. 8 A1, B1). In the samples, sclerenchyma tissue was formed toward the cortex from the vascular bundles. In the in situ specimen, the cell walls in this tissue are more thickened, indicating strong sclerification and lignification. The vascular bundles are highly developed, and the xylem vessels have thicker walls compared to the ex situ specimen. Additionally, the phloem elements in the in situ specimen are more abundant, with fiber cell walls thickened and more compactly arranged (Fig. 8 A2, B2). The protective tissue forming the outer layer of the stem consists of large cells in the ex situ specimen, whereas in the in situ specimen, these cells are relatively smaller and contain a higher concentration of

biologically active compounds. In both samples, it is observed that the guard cells in the stomata formed in the epidermis are positioned closer to the surface. On the inner side of these small-sized cells, a moderately sized sub-stomatal cavity has formed in the subepidermal layer (Fig. 8 A4, B4). Trichomes, as epidermal derivatives, are denser in the in situ specimen. Most of these trichomes are multicellular, elongated, and pointed tectorial trichomes. Additionally, secretory trichomes are present, including short to medium-length capitate trichomes. These trichomes consist of a glandular head positioned on a stalk composed of two, three, four, or more cells (Eroz Poyraz & Koca, 2007; Esmaeili et al., 2019) (Fig. 8 A3, B3).

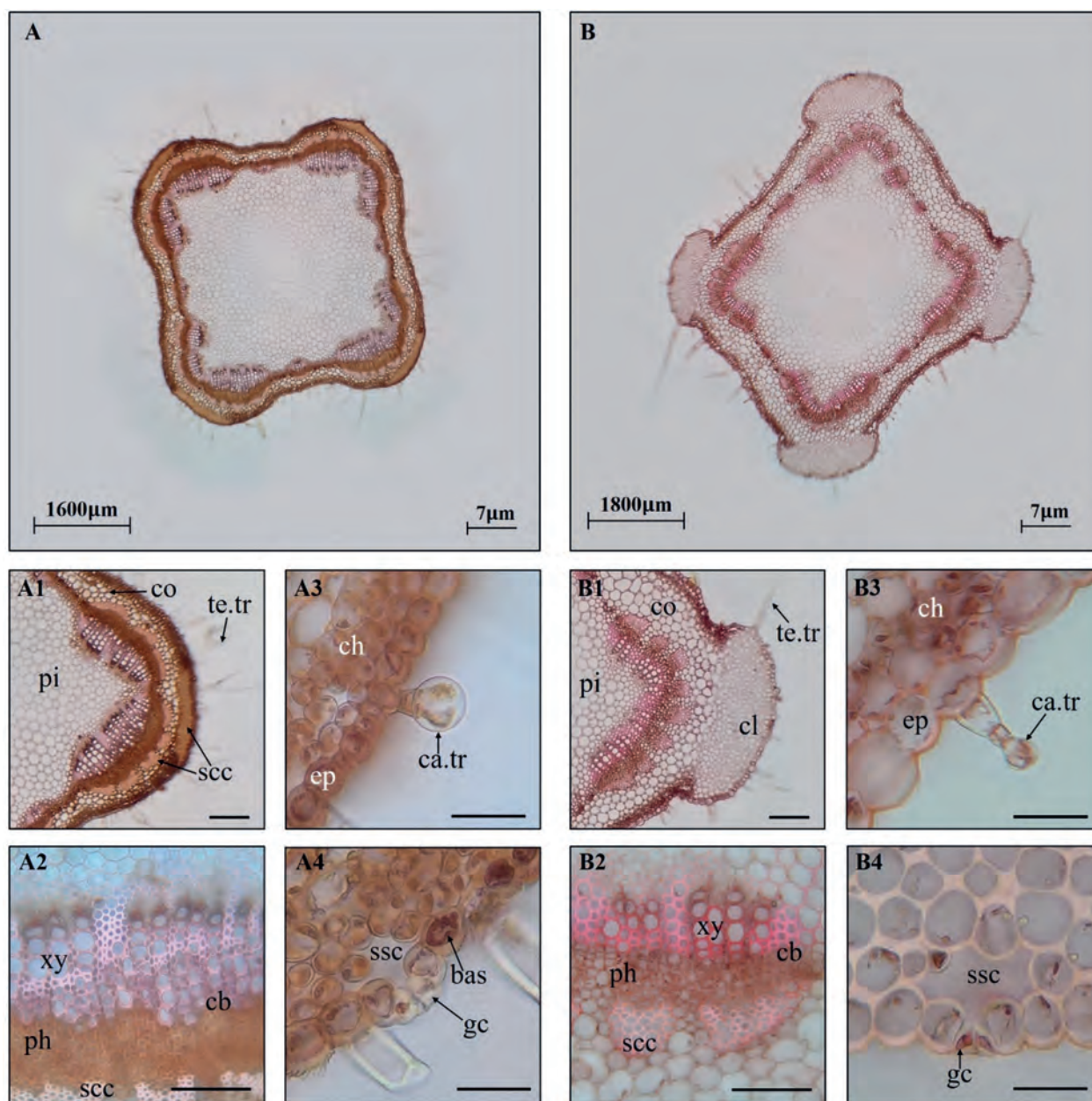


Figure 8. *Salvia nemorosa*. Stem. A (in situ), B (ex situ): General view (10x16); A1, B1: Ridges (40x); A2, B2: Collateral bundles (40x); A3, B3: Capitate trichome (100x); A4, B4: Stoma structure and metabolites in the epidermis cells (100x). ch-chlorenchyma; cl-collenchyma; co-cortex; pi-pith; scc-sclerenchyma; xy-xylem; ph-phloem; ca-cambium; bas-biological active substances; ca.tr-capitate trichome; te.tr-tectorial trichome; ep-epidermis; ssc-sub-stomatal cavity; gc-guard cell. (scale bar: A1, B1 – 200µm; A2, B2 – 100µm; A3-4, B3-4 –

Root. In the ex situ specimen of the *S. nemorosa* root, the central cylinder is large and asymmetrically positioned, denser on one side and oriented towards the cortex. This suggests that, due to environmental factors, the central cylinder in the ex situ sample is not centrally located but instead inclined toward the periphery, exhibiting an uneven expansion towards the cortical tissue (Fig. 9 A, B). In the central part of

the root xylem, protoxylem and metaxylem vessels, which are the first-formed elements, can be observed. In the in situ sample, the protoxylem vessels, arranged along radial axes, form four xylem rays, indicating a tetrarch structure in the primary vascular bundle. In contrast, the ex situ sample exhibits six xylem rays, corresponding to a hexarch structure. Additionally, in the ex situ specimen, a region composed

of mechanical cells has developed in the central part, containing several metaxylem vessels (Fig. 9 A2, B2). According to the arrangement of primary elements, the in situ sample has four large medullary rays within the xylem, while the ex situ sample has six. In the in situ specimen, these rays are composed of prosenchymatic parenchymal cells, whereas in the ex situ sample, the cells forming this tissue are relatively prismatic in shape. Microscopic observations of ergastic substances in the parenchyma cells were conducted in both samples (Fig. 9 A5, B5). The sections of xylem tissue, separated by medullary rays, are composed of large xylem vessels and densely arranged small libriform fibers between them (Kahraman et al., 2011; Xu et al., 2023). Additionally, numerous medullary rays, consisting of one or two cell rows, can be observed within these sections (Fig. 9 A1, B1). Anatomical analysis revealed the presence of granular substances within the libriform fibers of the in situ sample, whereas they were found in very small amounts in the second specimen (Fig. 9 A3, B3). In the xylem tissue, particularly in the central elements and some of those near the cortex, an orange-brown substance was observed filling the intracellular spaces. In

the in situ sample, a higher sequestration of the mentioned substance was observed. The xylem tissue is surrounded by phloem, within which medullary rays extend into the phloem, dividing it into sections (Fig. 9 A4, B4). In the root of the plant collected from the in situ environment, druse-shaped crystals were observed in the phloem parenchyma as well as in the cortical parenchymal cells located near the periderm. These crystals were less abundant in the ex situ sample. Anatomical investigations determined that sclerenchyma tissue had formed in the phloem region adjacent to the cortex (Özkan & Şenel, 2006). Visual analysis indicated that this tissue consisted of two groups of sclerenchyma fibers. The fiber walls in the phloem-facing region exhibited less thickening, whereas those closer to the cortex underwent intensive thickening, significantly reducing the diameter of the intracellular space. However, it can be clearly stated that the process of sclerification was more prominent in the in situ sample (Fig. 9 A6, B6). The cortex parenchyma cells in the in situ sample are smaller in size and accumulate more ergastic substances (Table 5). In contrast, the cells in the ex situ sample were larger and more elongated (Fig. 9 A7, B7).

Table 5

Quantitative characteristic of the roots of *Salvia nemorosa*, μm

Indicators	In situ (Mean $\pm$ SD)	Ex situ (Mean $\pm$ SD)
The thickness of the periderm	76,81 $\pm$ 2,33	68,53 $\pm$ 2,16
Diameter of the cortical parenchyma cells	32,62 $\pm$ 1,47	43,15 $\pm$ 1,78
Diameter of the xylem vessel	66,34 $\pm$ 3,15	79,43 $\pm$ 3,68

Discussion

In the in situ specimen of *Salvia nemorosa*, the amount of pectin and cellulose increased, leading to thickening and reinforcement of the collenchyma walls, characteristic of classical collenchyma structure. In the in situ specimen of the species, the complete thickening of collenchyma cell walls was considered a transitional stage toward sclerenchyma. This structural adaptation forms in response to the ecological conditions of the area and mechanical stress during plant development (Tutayuk, 1980).

Essential oils (etheric oils) accumulate in the leaves of *S. nemorosa*, primarily composed of diterpenoids and flavonoids (Koshovyi, 2012; Koshovyi et al., 2012). The accumulation of these substances in oil cells and secretory structures is distinctly visible. Microscopic studies revealed the presence of these substances in the epidermal cells of the leaf in the form of diffuse secretion. Additionally, intercellular diffuse secretion and homogeneous secretion were observed in the spongy and palisade parenchyma.

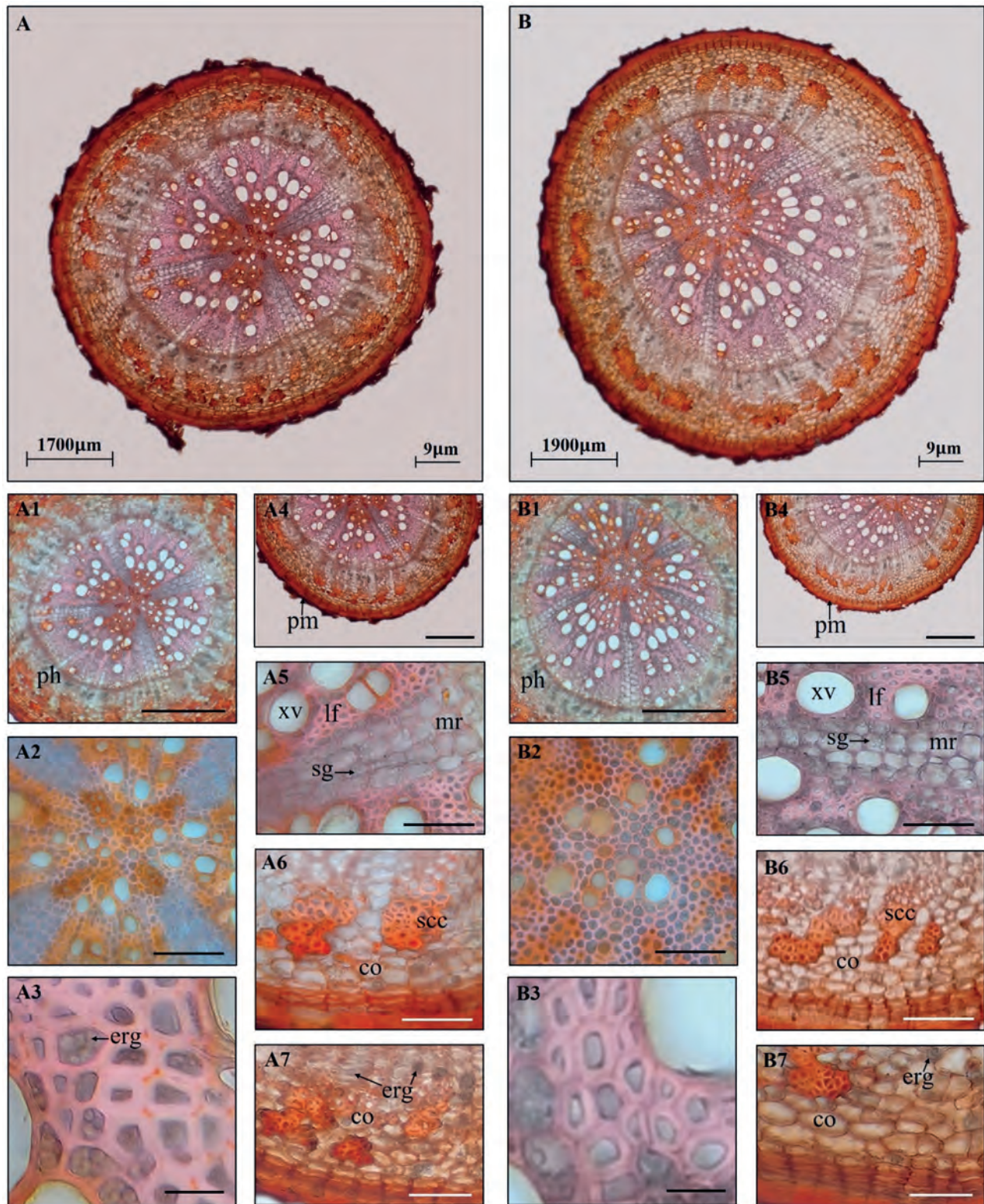


Figure 9. *Salvia nemorosa*. Root. A (in situ), B (ex situ): General view (10x16); A1, B1: Central cylinder (10x); A2, B2: Central part of xylem (40x); A3, B3: Metabolites accumulated in libriform fibers (a larger amount in the in situ sample) (100x); A4, B4: Part of the root (10x); A5, B5: Medullary ray (40x); A6, B6: Sclerenchyma tissue in the cortex (40x); A7, B7: The distribution of metabolites in the root cortex (40x). pm-periderm; co-cortex; scc-sclerenchyma; xv-xylem vessels; lf-libriform fibres; mr-medullary ray; dr-druse; sg-starch granules. ph-phloem; erg-ergastic substances. (scale bar: A1, B1 – 500; A2, B2 - 100µm; A3, B3 - 20µm; A4, B4 - 300µm; A5-7, B5-7 - 100µm)

Bagheri G. et al. (2016a) conducted an anatomical study on the petiole and stem of *S. nemorosa*. For this purpose, specimens were collected from regions with different altitudes in North Khorasan, Iran (Boujnord, Esfidan - 1561 m; Quchan, Oghazkohneh - 1800 m) and fixed in FAA solution. Hand-cut transverse sections were obtained from the samples and stained with green methyl and carmine dyes. The prepared materials were analyzed using a Labomed CZ500 light microscope. The results indicate the formation of two types of trichomes on the plant. Short glandular trichomes were found at a low frequency, and sparsely distributed simple hairs were also observed. In the ex situ specimen we studied, techtorial trichomes were similarly found in low numbers. However, in the in situ specimen, both techtorial trichomes and various types of glandular trichomes were densely distributed on the surface of the petiole (Fig. 10). According to foreign authors, the overall shape of the petiole is crescent-like, with five vascular bundles in the center and two on each side. Anatomical analyses of *S. nemorosa* petioles in both in situ and ex situ specimens revealed three vascular bundles in the central region, while two vascular bundles were present on each side, aligning with previous research findings. In the study by foreign researchers, the collenchyma in the corners of the stem was reported to consist of 6–8 layers of cells. Our microscopic analyses showed that in the in situ specimen, the collenchyma consisted of 5–6 layers of cells, whereas in the ex situ specimen, it comprised 12–13 layers. Bercu and colleagues (2012) investigated the leaf and petiole anatomy of two *Salvia* species (*Salvia nemorosa* and *Salvia nutans*) and their hybrid. Plant samples were collected from the coastal area of the Dobrudja region in Romania. Anatomical analyses revealed that the central vascular tissue in the petioles consisted of several conductive bundles. In *S. nemorosa*, the vascular system comprised two large bundles and one small bundle. In our study, the in situ sample exhibited two very large conductive bundles and one small bundle in the central part. In the ex situ sample, two large bundles and one small bundle were observed. In the study presented by foreign

authors, the large petiole bundles consisted of 11 xylem rays, while the small bundle contained 4 xylem rays, with each ray composed of 4–5 xylem vessels. In our anatomical analysis of the in situ petiole of *S. nemorosa*, the large bundles contained 20 xylem rays, each with 8–12 xylem vessels, whereas the small bundle had 6 xylem rays, each formed by 7–9 vessels. In the ex situ sample, the large bundles contained 15 xylem rays, while the small bundles had 6 xylem rays, with each ray composed of 4–6 xylem vessels. Our study included a comparative analysis of the in situ (Shusha) and ex situ (Ganja) conditions of *S. nemorosa* in Azerbaijan, as well as a comparison with in situ samples collected by foreign researchers from the Black Sea coast in the Dobrudja region of Romania. The results indicate that Azerbaijan's mountainous and temperate continental climate positively influences the biomorphological and ecophysiological characteristics of the plant, with Shusha samples exhibiting stronger development. This difference is primarily attributed to the uniqueness of Azerbaijan's climatic and ecogeographical conditions. The country encompasses nine climate types and diverse ecosystems, which enhance plant adaptation potential. Particularly in high-altitude areas like Shusha, the temperate continental climate, high insolation, clean air, and soil minerals contribute to the plant's structural and functional development. Comparative ecological-anatomical analysis shows that in Shusha samples, the development of collenchyma and sclerenchyma tissues in the petiole and leaf, the vascular system, and trichomes is more pronounced, increasing the plant's mechanical resilience. The greater differentiation of the vascular system optimizes water and nutrient circulation. Increased cuticle thickness minimizes water loss. In contrast, *S. nemorosa* samples from the Black Sea coast of Romania demonstrated relatively lower mechanical tissue development and weaker structural reinforcement. This suggests that Azerbaijan's climate and ecosystem conditions are more favorable for the growth of *S. nemorosa*. From an ecological-geographical perspective, Azerbaijan's climatic diversity, multi-climatic adaptation capacity, anatomical resilience

in mountainous environments, photosynthetic optimization in continental climates, and structural reinforcement regulated by ecological stress factors contribute to the formation of the specific structure observed in the in situ *S. nemorosa*. The anatomical structure of the petiole in the *S. nemorosa* specimens collected from the coastal area of the Dobrudja region by Bercu and colleagues closely corresponds only to the ex situ petiole structure of the *S. nemorosa* plants studied in Azerbaijan. As mentioned, the number of xylem rays and xylem vessels in the vascular system of our in situ sample significantly exceeds that of the in situ plant studied by Bercu and colleagues and the ex situ plant examined in our research. During their study, the authors observed capitate glandular and non-glandular trichomes on both the leaf and petiole surfaces, differing in shape and

size. They noted that non-glandular trichomes primarily consisted of three cells, though occasionally two or four cells were present. When compared with our findings, this type of covering trichome was also composed of two, three, or four cells, showing consistency. However, the trichomes in our examined plants were more abundant and densely formed on both the leaf and petiole, especially in the in situ samples. In the study by foreign authors, the collenchyma tissue in the abaxial region of the leaf's central vein area was reported to consist of 4–5 layers. Our anatomical analyses confirmed that in the in situ sample, the collenchyma tissue in the subepidermal area consisted of 4–5 layers, whereas in the ex situ sample, it comprised 2–3 layers. The authors observed that the leaf had a dorsiventral structure and was amphistomatic, which was also determined in our study.

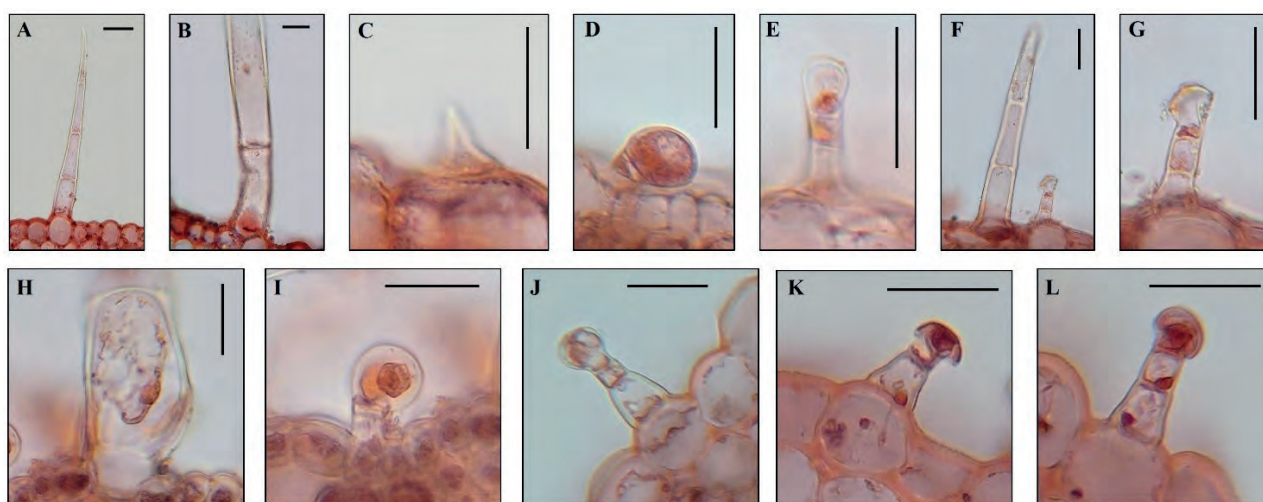


Figure 10. Various types of trichomes in *Salvia nemorosa*. A, B: Tectorial trichomes on the leaf; C: Conical trichomes on the leaf; D, E: Capitate trichome containing biologically active compounds on the leaf; F, G: Tectorial and capitate trichomes on the petiole; H: Tectorial trichome containing biologically active compounds on the stem; I–L: capitate trichomes containing accumulated substances on the stem; scale bars: 30μm

In the photomicrographic analysis of the ex situ sample of *S. nemorosa*, it was determined that the root had an eccentric central cylinder (Fig. 11). The microscopic image clearly shows that the central cylinder is asymmetrically positioned towards the left and has approached the cortex. The increased development of the sclerenchyma tissue in this direction is associated with enhanced mechanical stability of the root (Pandey, 2012; Prokhorenko et al., 2017). The

presence of an eccentric central cylinder in the ex situ sample can be considered as an adaptation to the stable conditions of the introduced environment.

In the in situ sample of *S. nemorosa* grown under Shusha conditions, the root's xylem development model was found to be tetraarch, while in the ex situ samples grown under Ganja conditions, it was hexarch. This difference is related to the degree of differentiation of the

xylem elements and the dynamics of ontogenetic development, which can be attributed to ecological factors in the growing conditions (such as soil moisture, temperature regime, mineral nutrition, and mechanical stress) (Sardarova, 2022a; Khubieva, 2024). The formation of a hexarch structure in the ex situ samples grown under Ganja conditions can be explained by the longer activity of xylem protoelements and

increased hydraulic conductivity. In contrast, the dominance of the tetraarch structure in the in situ samples grown under Shusha conditions is linked to the maintenance of an optimal balance between water transport and mechanical stability, which is suitable for the natural ecosystem. These results suggest that xylem differentiation is regulated by ecological plasticity and adaptation mechanisms.

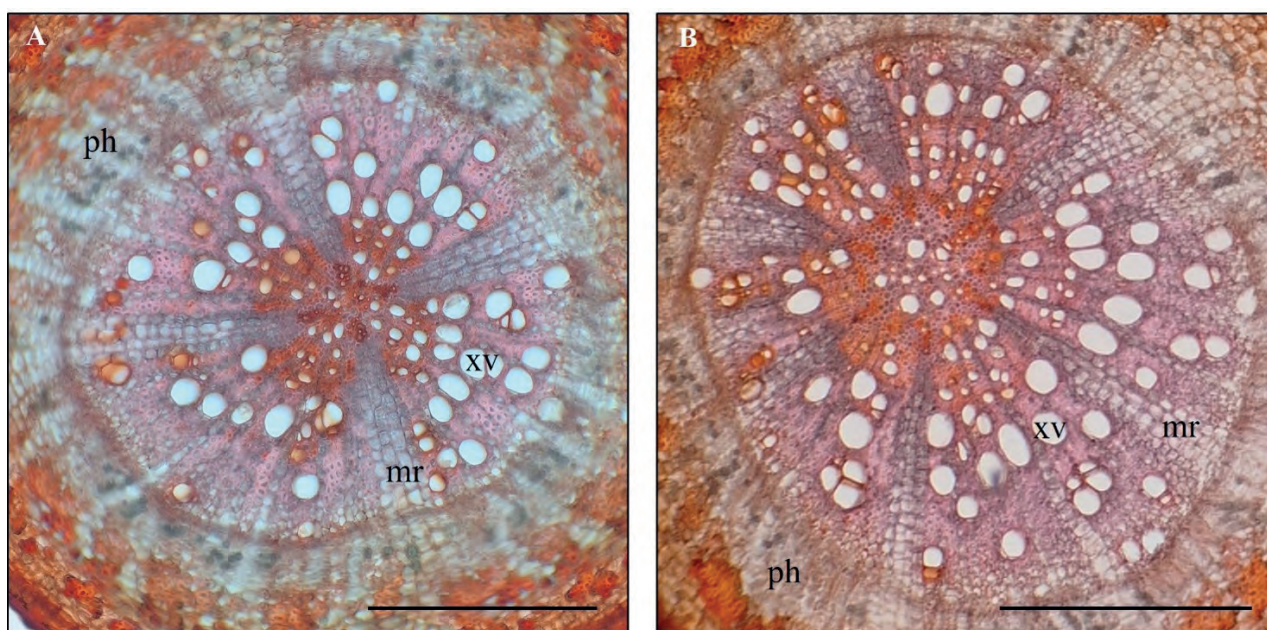


Figure 11. *Salvia nemorosa*. Central cylinder of the root (10x). A: in situ; B: ex situ; xv-xylem vessels; mr-medullary ray; ph-phloem; scale bar: 500μm.

In the root of *S. nemorosa* grown under in situ conditions, the parenchyma cells are small and relatively elongated, which can be associated with their high intracellular metabolic activity and the increased synthesis of biologically active substances (such as phenols, flavonoids, and terpenoids) for defense purposes. In contrast, under ex situ conditions, the reduction of stress factors results in larger and more elongated parenchyma cells, with a decrease in the amount of biologically active substances. Regarding the variation in the concentration of biologically active substances in both ecotypes, the high concentration of ergastic substances in the root cortex under in situ conditions indicates the plant's adaptation to stress (such as water scarcity, variations in soil conditions, and interactions with microorganisms) (Bertoft, 2017; Lata et al., 2021; Kolupaev & Blume, 2022; Apriyanto et al., 2022; Pramanik et al.,

2024). The decrease of these substances under ex situ conditions can be linked to the reduction of stress factors. In the root of the plant grown under in situ conditions, the presence of granular inclusions in the libriform fibers was observed. This may be related to the accumulation of intracellular metabolites or the specific differentiation of structural components.

Sclerenchyma in the cortical regions of the root is more differentiated, which can be regarded as an adaptation for protection against mechanical impacts and ecological factors. Sclerenchyma tissue consists of lignified cells that enhance mechanical stability, and its higher presence in the in situ conditions is likely the result of adaptation to ecological factors such as soil density and water scarcity. The more intensive development of sclerenchyma tissue in the root of *S. nemorosa* grown under in situ conditions can be explained by the influence of

mechanical stress factors in the natural habitat. Under ex situ conditions, however, due to the optimal cultivation conditions, the amount of sclerenchyma decreases, as the plant no longer requires additional mechanical support.

Conclusion

The eccentric differentiation of the central cylinder in the root of the ex situ sample of *Salvia nemorosa* is of theoretical significance in terms of the plant's adaptation to optimal ecological conditions and the regulation of its defense mechanisms. On the side where the central cylinder is oriented, the development of more sclerenchyma tissue in the cortex forms a structure that can contribute to increased mechanical stability and functional adaptation. The formation of tetraarch protoxylem in the in situ sample of *S. nemorosa* and hexarch protoxylem in the ex situ sample represents the differentiation of vascular system elements, which is an evolution of ecological anatomy and an indicator of the ecotope. Anatomical analyses have revealed that sclerenchyma tissue is intensely developed in the root of *S. nemorosa*. The increased presence of mechanical tissue serves to enhance the plant's resistance to the ecological pressures of mountainous terrain. Granular inclusions have been found in the root libriform

fibers of the *S. nemorosa* sample growing in the in situ conditions, which is a unique finding and represents the plant's ecotypic adaptation structure. In the in situ sample of *S. nemorosa*, the active biosynthesis of metabolites, the formation of defensive reactions as an ecological plasticity mechanism, and the differentiation of sclerenchyma in plants in terms of resistance to ecological stress are directly related to the unique mountainous climatic factors of the city of Shusha, representing a structural adaptation.

Considering the relevance in the context of climate variability, the comparative ecological anatomical study of structural adaptations such as mechanical tissues, vascular variations, stomatal and trichomal functionality, etc., of *S. nemorosa* species under in situ and ex situ conditions is an important scientific investigation. The results obtained in this study serve as an example in assessing the adaptation potential of flora elements to climate variability in issues such as the sustainability of biodiversity in ecosystems, plant adaptation mechanisms in various ecosystems, and so on. This is a unique fact that will be presented to the contemporary international approach "COP". This work plays an important practical and theoretical role in future climate variability resilience strategies.

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CHARACTERISTICS OF DESERT VEGETATION OF THE COASTAL PART OF SALYAN REGION (SOUTH-EASTERN PART OF AZERBAIJAN, SHIRVAN LOWLAND)

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Abstract. *The article describes the vegetation of the coastal area of the Salyan region. Background plant communities are formed by the edificators *Salsola dendrodes* Pall., *S. nodulosa* (Moq.) Iljin, *S. ericoides* M. Bieb., *S. crassa* M. Bieb., *Halocnemum strobilacem* (Pall.) M. Bieb., *Artemisia fragrans* Willd., *Petrosimonia brachiata* Pall. Bunge. The phytocenotic features of dominants and edificators of saltwort desert phytocenoses, as well as the species composition of ephemerals, are discussed. The results of the gradient distribution of communities from the seashore to the mainland are presented. Information on invasive and endemic species in the study area is provided. The article also examines the main plant types in the region and their distribution in relation to drought, moisture, and salinity levels. The impact of anthropogenic factors on these plant types is also discussed.*

Keywords. *Salsola vegetation, desert communities, coastal strip, anthropogenic factor, alien plants, endemics*

Introduction

Most of the Salyan region is occupied by desert and semi-desert vegetation types. The next most important are shrub and aquatic-marshy vegetation, represented mainly by tamarix (*Tamarixeta*) and reed (*Phragmiseta*) communities, concentrated mainly in the riverine areas of the region, along narrow water channels, marshy and other water basins (Melikov, 2006). Salyan vegetation serves as a winter fodder reserve for livestock farms (Kasimzade, 2020). The practice of winter pasture exploitation in the lands of the Shirvan Lowland dates back to ancient times. The growth of valuable fodder shrubs, semi-shrubs, and forbs continues to provide feed for cattle and small cattle to this day (Shennikov, 1964). Since the mid-20th century, cotton growing and other types of agriculture have also increased in this region

(Grossheim, 1948).

Along with the positive aspects, there are “side effects” that cause overloading of land areas, reduction of winter pasture areas, reduction of their qualitative and quantitative species composition, and expansion of naturalized alien plants (Mirkin, Naumova, 2001). The vegetation of the coastal part of the region is interesting due to the transgression of the Caspian basin and the active exploitation of the coastal strip. To protect and preserve some of the flora and fauna of the Shirvan Lowland, the Shirvan National Park was established in 2003 in the administrative districts of Salyan and Neftchala regions (Azerbaijan National Encyclopedia, 2007).

In recent years, studies of the vegetation of the Salyan region have been carried out within the framework of studying the features of the vegetation cover of the Shirvan Lowland

(Huseynova, 2024; Qurbanov, 2024). The researchers focused on floristic, eco-geobotanical, and synecological aspects. However, these studies were comprehensive and covered the entire Shirvan Lowland. The purpose of our research was to study the saltwort desert and semi-desert phytocenoses located in the coastal zone of the Salyan region.

Materials and methods

The study area is located in the flat southern part of the republic, crossed by one of Azerbaijan's largest rivers, the Kur River. It borders on the Caspian Sea in a small settlement and is at an altitude of -25 m relative to sea level. The zonal soils in the area are saline and slightly saline, including gray-brown, gray-meadow, and meadow-marsh soils. There are also clayey salt marsh soils with varying groundwater levels

(Azerbaijan National Encyclopedia, 2007).

The climate of the region is moderately hot with extremely dry summers, greatly influenced by the nearby Caspian Sea (Shikhlinsky, 1968). The average temperature ranges from +8.5°C in winter to +33.5°C in summer, with annual precipitation typically between 250-400 mm. The coldest days occur at the end of January (-1°C to -5°C), while the warmest days are at the end of August and beginning of September (43°C) (Museibov, 1998).

The study focused on the phytocenoses of the coastal part of the Salyan region within a 0-5 km radius from the coastline (Fig. 1). The vegetation in this area is closely tied to the ecotope conditions and consists of haloxerophytic saltworts, xeromesophytic, and mesoxerophytic ephemerals.

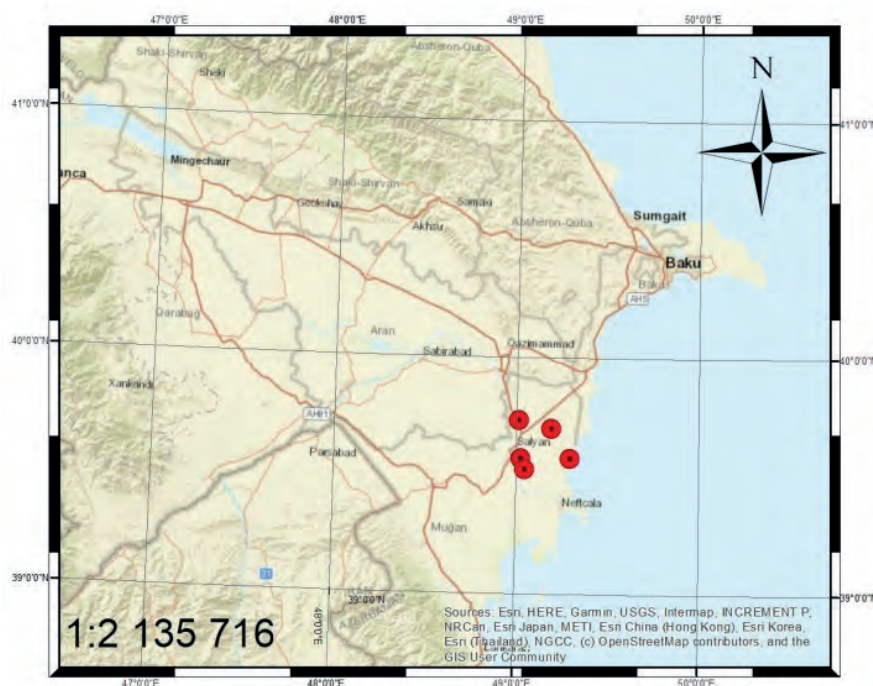


Figure 1. Research routes

The study was conducted in the early spring, early summer, late summer, and early autumn field seasons of 2024 using the route-reconnaissance method. To conduct a comparative analysis of vegetation in anthropogenically disturbed and undisturbed areas, the sample plot method with standard geobotanical descriptions (projective cover in %, abundance according to

Braun-Blanquet, 1964, registration of species composition) as outlined by Lavrenko & Korcha-gina (1959-1974) was utilized. The plots were 100 x 100 m in size and were further divided into smaller plots of 2x5 m to account for the diffuse distribution of plants. The frequency of occurrence was determined by calculating the ratio of plots with a given species/community

to plots without a given species/community. If necessary, the plots were mapped, considering the distribution and species composition of plants based on Pedrotti (2013). *Salsola* phytointicators were used as indicators of soil salinity, following the methods outlined by Volobuev (1959) and Abduiev (1973). Plant species were identified using the www.worldfloraonline.org database and the Flora of Azerbaijan (1950-1961).

Results and Discussion

The survey revealed the presence of the following types of communities in the area: Annual saltwort-forb coastal desert on wet sands (Total Projective Cover (TPC) 30% in early spring, early summer, TPC 40% in late summer - early autumn). Salt marsh semi-shrub desert on clayey gray-brown soils with a high groundwater table (TPC 35% in early spring, early summer, TPC 30% in late summer - early autumn). Annual saltwort desert on saline, variably moist or dry grey-brown soils with dwarf semi-shrubs, sub-shrubs, and perennial forbs (TPC 60% in early spring, early summer, 50% in late summer

- early autumn). Distance from the coastline is 3-5 km, with a length of 2 km. *Salsola* small-shrub, dwarf semi-shrub desert on dry grey-brown soils with wormwood and ephemerals (TPC 60% in early spring, early summer, TPC 50% in late summer - early autumn). Distance from the coastline is 1-2.5 km, with a length of 1.5 km. Wormwood - ephemeral semi-desert on dry gray-brown soils (TPC 70% in early spring, early summer, 50% in late summer - early autumn). Found in hilly areas (hills height 50-100 m) and flat areas. Distance from the coastline is 3-5 km, with a length of 2 km. Wormwood - saltwort-ephemeral desert on dry gray-brown soils (TPC 40% in early spring, early summer, TPC 20% in late summer-early autumn). Also found in hilly areas and at the foot of hills. Distance from the coastline is 3-4.5 km, with a length of 1-1.5 km. Forb vegetation (TPC 40% in early spring, early summer, TPC 20-30% in late summer - early autumn). Distance from the coastline is 0-5 km. From an economic perspective, options 1, 2, 3, and 4 are the most valuable for animal husbandry (Fig. 2).

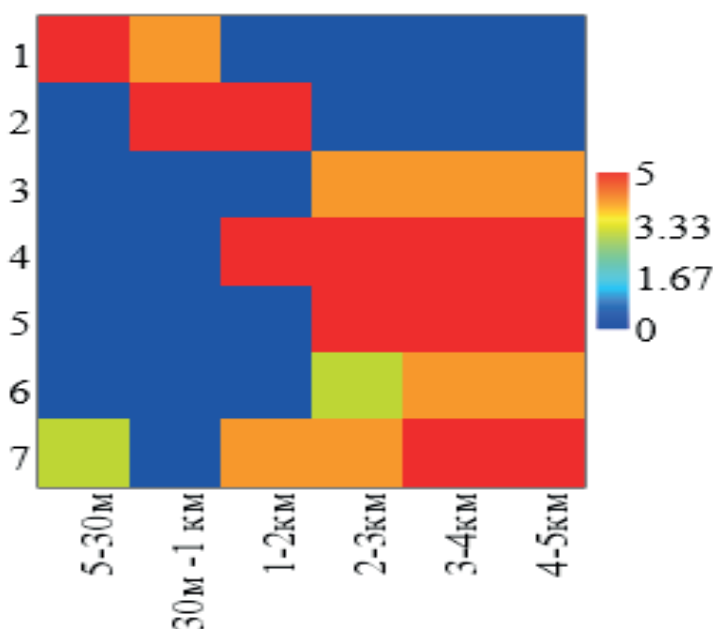
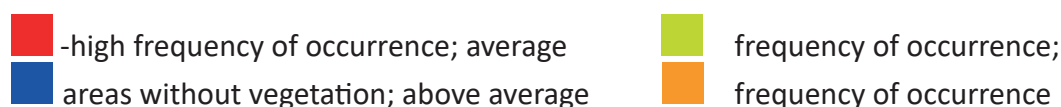


Figure 2. Matrix of community distribution along the coast-continent gradient, X-axis – distance from the sea, Y-axis – plant community variant:



Variants of plant communities:

1. Annual saltwort-forb coastal desert on wet sands (TPC 30% in early spring, early summer, TPC 40% in late summer - early autumn).
2. Salt marsh semi-shrub desert on clayey gray-brown soils with a high occurrence of groundwater.
3. Annual saltwort desert on saline, variably moist or dry gray-brown soils with the participation of dwarf semi-shrubs and perennial forbs.
4. Saltwort small shrub, dwarf semi-shrub desert on dry gray-brown soils with an insignificant participation of wormwood and ephemerals.
5. Wormwood-ephemeral semi-desert on dry gray-brown soils of hilly areas, as well as on flat areas.
6. Wormwood-saltwort-ephemeral desert on dry gray-brown soils.
7. Mixed-herb vegetation.

The matrix, compiled based on occurrence and presented in Figure 2, shows an uneven distribution of communities as follows: 1. Annual saltwort vegetation has the highest occurrence and projective cover at a distance of 5-30 m from the coastline (length 25 m). 2. Salt marsh semi-shrub desert on clayey gray-brown soils with a high groundwater table is most localized at a distance of 30 m - 1 km from the coastline (length 700 m). 3. Annual saltwort desert on saline variably moist or dry gray-brown soils with dwarf semi-shrubs, semi-shrubs, and perennial forbs spreads at a distance of 3-5 km from the coastline (length 2 km). 4. Saltwort small shrub, semi-shrub desert on dry gray-brown soils with insignificant participation of wormwood and ephemerals is moderately present at a distance of 2.5 - 5 km from the coastline (length up to 3 km). 5. Wormwood-ephemeral semi-desert on dry gray-brown soils on plateau areas of mesorelief at a distance of 2.5-5 km from the coastline (length 2.5 km). 6. Wormwood-saltwort-ephemeral semi-desert on dry gray-brown soils of hills and foothills is located at a distance of 3-4.5 km from the coastline (length 1-1.5 km). 7. Forb vegetation is found in all areas of the gradient, with a distance from the coastline

of 0-5 km, and a change in species composition may occur (an increase in the proportion of plants in the area of the mainland, distance 3-5 km from the coastline). We attribute this distribution to soil conditions, which we diagnosed visually, mechanically, and through changes in abundance or the presence/absence of phytoindicators.

Edificators and dominants of the studied communities are *Artemisia fragrans* Willd. (a perennial forb plant, a salinity-resistant xerophyte, a representative of the family Asteraceae Guerke), *Salsola dendroides* Pall. (salinity-resistant, drought-tolerant, but preferring moist substrate, halomesoxerophyte, representative of the family Chenopodiaceae Vent.= Amaranthaceae Juss.), *Salsola nodulosa* (Moq.) Iljin (salinity-resistant, drought-tolerant, haloxerophyte - subshrub, representative of the family Chenopodiaceae Vent.= Amaranthaceae Juss.), *Salsola ericoides* M.Bieb. (salinity-resistant, drought-tolerant, haloxerophyte - subshrub, representative of the family Chenopodiaceae Vent.= Amaranthaceae Juss.), *Suaeda dendroides* (C.A.Mey.) Moq. (salinity-resistant, drought-tolerant haloxerophyte - shrub, representative of the family Chenopodiaceae Vent.= Amaranthaceae Juss.), *Halocnemum strobilaceum* (Pall.) M.Bieb. (salinity-resistant, drought-tolerant, gravitating towards conditions of the upper occurrence of groundwater, haloxerophyte, representative of the family Chenopodiaceae Vent.= Amaranthaceae Juss.), *Salsola crassa* M.Bieb., *Petrosimonia brachiata* Pall.Bunge, (salinity-resistant, drought-tolerant, haloxerophytes - annuals, often indicators of secondary salinity, representatives of the family Chenopodiaceae Vent. = Amaranthaceae Juss.), *Suaeda confusa* Iljin, *S. altissima* (L.) Pall., *Salicornia europea* L. (salinity-resistant, drought-tolerant, but gravitating to a moist substrate, halohygrophytes - annuals, representatives of the family Chenopodiaceae Vent. = Amaranthaceae Juss.). Taking into account the dominant-determinate principle, we identified the communities presented in Table 1.

Table 1

Landscape plant communities of the coastal part (zone 0-5 km)

Name of plant community	Frequency of occurrence (%)	Ecotope conditions
<i>Artemisia fragrans</i> + <i>Ephemeraceae</i>	70	Slightly saline semi-desert on dry grey-brown soils. Mainly on hills
<i>Artemisia fragrans</i> + <i>Salsola nodulosa</i> + <i>Ephemeraceae</i>	40	Wormwood-saltwort semi-desert on dry saline grey-brown soils. Mainly on hillsides.
<i>Salsola dendroides</i> + <i>Salsola crassa</i> + <i>Ephemeraceae</i>	80	<i>Salsola</i> semi-desert on dry gray-brown soils with highly saline upper soil layer. On plateau areas of mesorelief.
<i>Salsola nodulosa</i> + <i>Suaeda dendroides</i> + <i>Ephemeraceae</i>	20	<i>Salsola</i> desert on dry saline gray-brown soils. On plateau areas of mesorelief.
<i>Halocnemum strobilaceum</i>	20	Saline desert on clayey highly saline soils. On plateau areas of mesorelief.
<i>Salsola dendroides</i> + <i>Salsola ericoides</i> + <i>Ephemeraceae</i>	30	<i>Salsola</i> desert on dry saline gray-brown soils. On plateau areas of mesorelief.
<i>Suaeda confusa</i> + <i>Suaeda altissima</i>	20	Saline desert on clayey highly saline soils. On plateau areas of mesorelief and along the coastline.
<i>Herbosa</i>	80	Mixed grass and cereal groups. Mainly on hills and hillsides.

We divided the identified communities into semi-desert and desert types. Then, considering the biomorph and ecotope conditions, we further categorized them into: 1. communities of highly saline dry gray-brown soils, 2. communities on slightly saline dry gray-brown soils, 3.

communities on wet clayey salt marshes, and 4. coastal halophilic meadow communities. Throughout the year, we documented the species listed in Table 2 within desert and semi-desert phytocenoses.

Table 2

Summary list of species composition of botanical groups in the zone 0-5 km from the coastline

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
Cereals			
<i>Hordeum murinum</i> subsp. <i>leporinum</i>	2	15	60
<i>Sphenopus divaricatus</i>	2	20	50
<i>Lolium rigidum</i> Gaudin.	1	15	40
<i>Lathyrus pannonicus</i> subsp. <i>collinus</i>	1	17	10
<i>Aegilops cylindrical</i> L.	2	20	40
<i>Bromus rubens</i> subsp. <i>rubens</i>	2	14	40
<i>Bromus japonicus</i> subsp. <i>japonicus</i>	2	12	30

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
<i>Echinochloa crus gale</i> subsp. <i>crus gale</i>	2	15	40
<i>Catabrosella humilis</i>	1	10	10
<i>Poa bulbosa</i> L.	1	15	5
Saltworts			
<i>Salicornia europaea</i> L.	1-2	15	10
<i>Suaeda altissima</i> (L.) Pall.,	1-2	35	10
<i>Suaeda confusa</i> Iljin.	1-2	20-25	10
<i>Halocnemum strobilaceum</i> (Pall.) M.Bieb.	3-4	45	30
<i>Petrosimonia brachiata</i> Pall. Bunge	3-4	25	60
<i>Salsola ericoides</i> M.Bieb.	2-3	45-50	40
<i>Salsola nodulosa</i> (Moq.) Iljin	2-3	35-45	50
<i>Salsola dendroides</i> Pall.	4	50-70	80
<i>Suaeda dendroides</i> (C.A.Mey.) Moq.	3	40-50	50
Legumes			
<i>Medicago minima</i> (L.) L.	2	5-10	30
<i>Medicago orbicularis</i> (L.) Bortal.	1-2	17-20	20
Mixed herbs			
<i>Chenopodium album</i> Bosc ex Moq	2	35	50
<i>Crepis micrantha</i> Czerep.	1-2	10	20
<i>Limonium meyeri</i> (Boiss.) Kuntze	2	15-20	60
<i>Psylliostachys spicata</i> (Willd.) Nevski	2-3	10-15	50
<i>Cerastium arvense</i> Schltl.	2	5	20
<i>Rumex angustifolium</i> Campd.	1	20-24	10
<i>Helianthemum salicifolium</i> (L.) Mill	1-2	8-10	10
<i>Plantago atrata</i> subsp. <i>atrata</i>	1-2	10	20
<i>Spergularia diandra</i> (Guss.) Heldr	2	10	20
<i>Myosotis linearis</i> Colla	2	5-8	20
<i>Scutellaria</i> sp	1	10	10
<i>Potentilla supina</i> Michx	1-2	10	5
<i>Tripolium pannonicum</i> subsp. <i>tripolium</i>	1	15	5

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
<i>Frankeniahirsute</i> L.	1-2	18	10
Total species			
Wormwood-ephemeral, wormwood-saltwort-ephemeral semi-desert communities			
Cereals			
<i>Hordeum murinum</i> subsp. <i>leporinum</i>	2	15	60
<i>Eremopyrum orientale</i> (L) Jaub.& Spach	2-3	15	20
<i>Sphenopusdivaricatus</i> (Gouan) Rchb.	2	20	50
<i>Lolium rigidum</i> Gaudin	1	15	40
<i>Poa bulbosa</i> Steud.	1-2	15	30
<i>Bromussterilis</i> L.	2	18	50
<i>Bromusjaponicus</i> Thunb. subsp. <i>japonicus</i>	2	18	60
<i>Sclerochloa dura</i> (L) P.Beauv.	2	3-5	50
<i>Aegilops squarrosus</i> L.	2-3	16	50
<i>Avena pilosus</i> synonym of <i>Cyperus pilosus</i> Vahl	2-3	20	40
<i>Trachynia dystachya</i> (L) Link.	2	7-10	30
<i>Bromus rubens</i> subsp <i>rubens</i>	2-3	15	30
<i>Echinochloa crus galli</i> subsp <i>crus galli</i>	3	12	50
<i>Catabrosella humilis</i> (M.Bieb.) Tzvelev	2	18	40
<i>Festuca myuros</i> L.	1	10	5
<i>Phalaris minor</i> Retz.	2	15	40
<i>Phleum paniculatum</i> Huds.	2	18	30
<i>Agriopyrum caninum</i> (L.) Pall. ex Hegi	2-3	18-20	30
<i>Rostrariacristata</i> (L.) Tzvelev	1-2	15	50
Saltworts			
<i>Salsola nodulosa</i> (Moq.) Iljin	2	35-45	30
<i>Salsola dendroides</i> Pall.	2	50-70	50
<i>Suaeda dendroides</i> (C.A.Mey.) Moq.	1-2	40-50	30
<i>Petrosimonia brachiata</i> Pall. Bunge	1-2	10-15	10
Legumes			
<i>Medicago minima</i> (L.) L.	2	5-10	30

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
<i>Medicago orbicularis</i> (L.) Bartal.	1-2	17-20	20
<i>Medicagorigidula</i> (L.) All.	2	15	20
<i>Trigonellamonspeliensis</i>	2	18	40
<i>Trifoliumarvense</i> Michx.	2-3	10	40
<i>Trifoliumretusum</i> L.	2	12	30
<i>Alhagipseudalhagi</i> subsp. pseudalhagi	2	45	50
<i>Cichoriumintybus</i> L.	1	40	5
<i>Viciamonantha</i> subsp. <i>monantha</i>	1-2	40	15
Mixed herbs			
<i>Artemisia fragrans</i> Willd.	4	45	90
<i>Bupleurum jerardii</i>	1-2	12	20
<i>Calendula persica</i> C.A.Mey	2	10	30
<i>Adoniaaestivalis</i>	1-2	10	30
<i>Adonis binertii</i>	1	8-10	20
<i>Alyssum campestre</i> Hoffm.	2	10	50
<i>Seneciovernalis</i> Franch	2	21	20
<i>Filagospathulata</i> C.Presl	2	10	20
<i>Hirschfeldia incana</i> (L.) Lagr.-Foss.	2	16	5
<i>Alyssum dessertorum</i>	3	20	20
<i>Lepidiumperfoliatum</i> L.	2-3	16	20
<i>Cerastiumarvense</i> Schltldl.	2	15	10
<i>Papaverpersicum</i> Hort.Dijon Elkan	1-2	15	10
<i>Crepisparviflorum</i>	3	5	20
<i>Carduusarabicus</i> Jasq.ex Murray	2	30	5
<i>Carthamus lanatus</i> L.	1-2	25	5
<i>Cirsium ciliatum</i> - Piper permucronatum var. <i>ciliatum</i> D. Monteiro & E.F.Guim.	1	15	5
<i>Plantago lanceolata</i> L.	3	15	40
<i>Psylliostachys spicata</i> (Willd.) Nevski	2-3	10-15	5
<i>Erodium cicutarium</i> (L.) L'Hér.	3	12	30
<i>Caucalis lappula</i> Grande	1	16	20
<i>Cerastium arvense</i>	2	15	20
<i>Chamaemelum praecox</i>	3	10	20

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
<i>Galium tenuissimum</i> M.Bieb.	2	12	20
<i>Geranium molle</i> G.Gaertn., B.Mey. & Scherb.	3	10	70
<i>Sisim brium</i> sp	1	20	10
<i>Limeum myosotis</i> var. <i>rotundifolium</i> Friedrich	2-3	5	50
<i>Crepis froelichiana</i> DC. ex Fro-el.	3	15-25	70
<i>Capsella bursa pastoris</i> subsp. <i>bursa-pastoris</i> Medik.	2	10-19	70
<i>Taraxacum desertorum</i> Schischk.	2-3	10-15	60
<i>Falcaria sioides</i> Bernh.	2	20	10
<i>Spinacea tetrandra</i> Roxb.	1	30	20
<i>Capparis spinosa</i> L.	2	30	10
<i>Xanthium strumarium</i> Lour.	1	20	10
<i>Xanthium spinosum</i> L.	1-2	30	10
<i>Erigeron Canadensis</i> Brot.	1	15	5
<i>Rapistrum rugosum</i> (L.)All.	2	15	10
<i>Tragopogon graminifolius</i> DC.	2	30	50
<i>Veronica didima</i> Ten.	2	10	60
Saltworts			
<i>Salsola dendroides</i> Pall	1-2	40	30
<i>Salsola nodulosa</i> Moq.Iljin.	2	35	40
<i>Petrosimonia brachiata</i> Pall. Bunge.	3	10-15	10
Total species			
Species composition of coastal vegetation			
Cereals			
Hordeum murinum subsp. leporinum	2	15	10
<i>Anisantharubens</i> (L.) Nevski	2	15	10
<i>Sphenopusdivaricatus</i> (Gouan) Rchb.	2	20	20
<i>Loliumrigidum</i> Gaudin	1	15	50
Saltworts			
<i>Salicornia europea</i> L.	1-2	15	10
<i>Suaeda altissima</i> (L.)Pall	2-3	35	40
<i>Suaeda confusa</i> M.Bieb.	2	20-25	30
Mixed herbs			

Salsola semi-shrub, semi-shrub, subshrub desert communities			
Species name and botanical group	Abundance	Height(cm)	Frequency of occurrence (%)
<i>Tripolium pannonicum</i> subsp. <i>tripolium</i>	3	18	30
<i>Senecio vernalis</i> Franch.	2	12	10
<i>Lepidium perfoliatum</i> L	2-3	16	20
<i>Tamarix ramosissima</i> Ledeb.	1	150	5
<i>Amaranthus retroflexus</i> L	1	35	5
<i>Capsella bursa pastoris</i> Medik.	2	10-19	70
<i>Geranium molle</i> G.Gaertn., B.Mey. & Scherb.	3	10	70
<i>Plantago atrata</i> subsp. <i>atrata</i>	1-2	10	60
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	2	200-250	40
<i>Spergularia diandra</i> (Guss.) Heldr.	3	10	20
<i>Veronica didyma</i> Ten.	2	10	60
Total species			

Based on the summary lists provided, the species composition of desert and semi-desert communities varies in terms of plant numbers. The semi-desert variant typically has an optimal abundance of 2-3 plants. However, there are ephemerals such as *Eremopurum orientale*, *Chamaemelum praecox*, *Aster tripolium*, *Alchagi pseudialchagi*, *Spergularia diandra*, and *Capsella bursapastoris*, which, despite being abundant, have low occurrences in phytocenoses. On the other hand, there are plants like *Lolium rigidum* and *Plantago saxatilis* with low abundance but high occurrence, indicating a diffuse distribution likely influenced by ecotop conditions. Further investigation is needed to explore this phenomenon.

In certain areas of the territory, alien plants *Xanthium strumarium*, *X. spinosum*, and *Erigeron canadensis*, all of North American origin, have been identified. Among these,

X. spinosum and *E. canadensis* are xeromesophytes, while one species is a mesoxerophyte, showing tolerance to arid conditions. Currently, these plants have low abundance and occurrence, likely due to recent introduction or challenging growth conditions like substrate salinity, weak moisture levels, and high solar radiation. They are typically found in areas with mild surface salinization or deep soil salinity.

As mentioned earlier, there is a noticeable gradient in plant distribution from the coastline towards the mainland, particularly within the 0-5 km zone. This gradient is closely linked to ecotop conditions such as salinity, groundwater depth, and soil type (see Fig. 3).

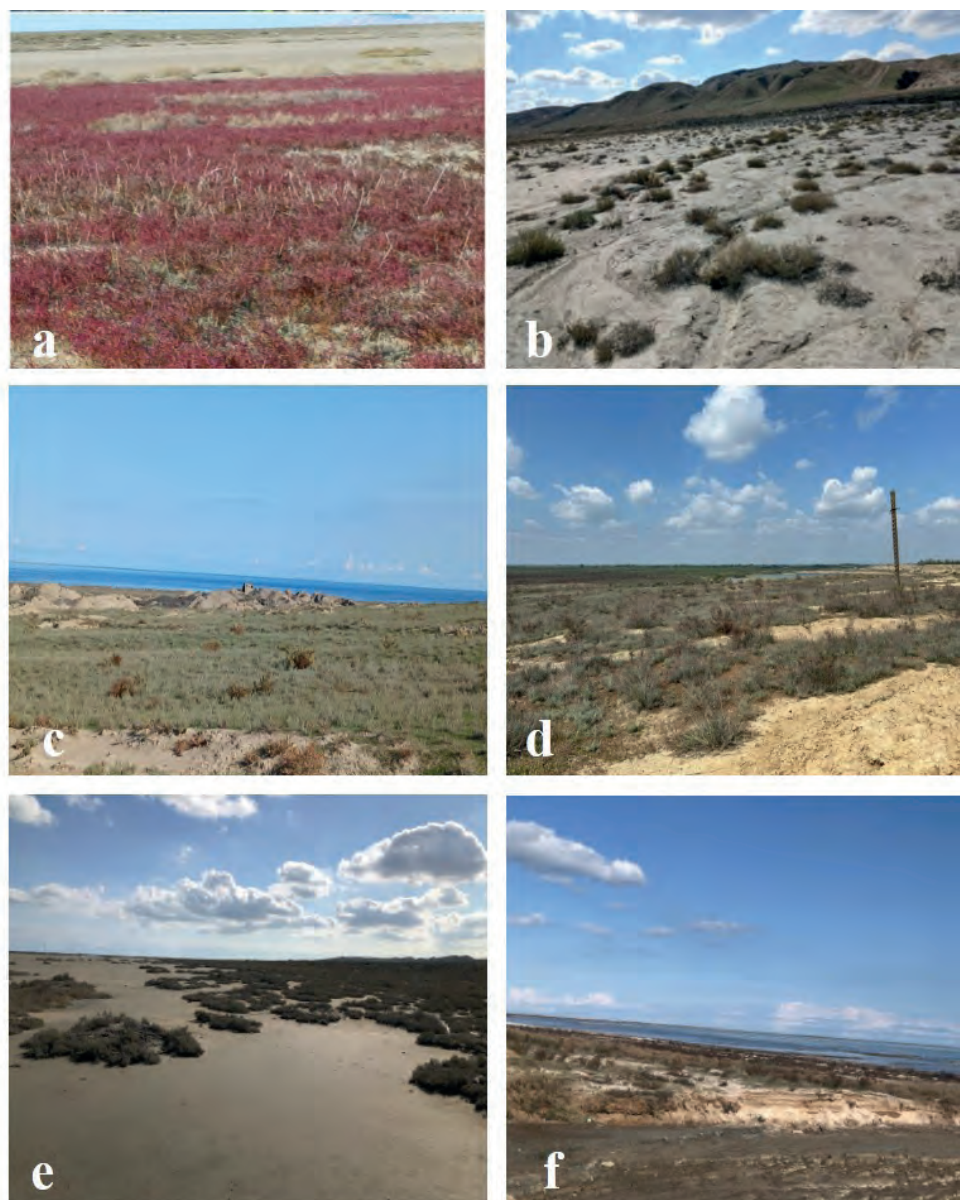


Figure 3. Desert semi-desert landscapes of the Salyan region

- a) One year associations: *Suaeda confuse*.
 - b) Saltwort desert at the foot of the hills with semi-desert wormwood-ephemeral, wormwood-saltwort communities;
 - c) Annual-saltwort desert with dominance of *Suaeda altissima*;
 - d) Wormwood semi-desert near the coastal strip;
 - e) Wet salt marshes with participation of *Halocnemum strobilaceum*;
 - f) Saltwort vegetation near the coastal zone
- Conclusion

Field studies conducted in the coastal part of the Salyan region identified the landscape plant associations of desert and semi-desert

vegetation types. It was found that three North American alien species—*Xanthium strumarium*, *X. spinosum*, and *Erigeron canadensis*—have become naturalized in the flora of Azerbaijan. These plants primarily migrate within slightly saline semi-desert wormwood-ephemeral communities, with wind currents acting as the means of their seed dispersion. Clay salt marshes populated by *H. strobilaceum*, along with communities containing *Salsola dendroides*, *S. ericoides*, and *Suaeda dendroides*, are inaccessible to these alien species due to the high salinity of the substrate. The endemic *Salsola nodulosa*, found in the Caucasus, forms valuable forage formations located 3 to 5 kilometers

from the coastline. The study of coastal vegetation revealed a gradient distribution of plant types, correlated with moisture levels, salinity, and varying degrees of human impact. The desert and semi-desert communities are in

satisfactory condition due to the absence of grazing. However, the immediate coastline is littered, and the vegetation appears to be in a depressed state, likely as a result of fishing activities.

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CONTENTS

Shakir Gasimov, Gunel Ramazanova, Shabnam Isayeva

MORPHOPHYSIOLOGICAL ANALYSIS OF ORGANOGENESIS OF SOME VARIETIES OF THE GENUS
CYMBIDIUM UNDER CLOSED CONDITIONS 4

**Salman Majeed, Sehrish Rubab, Yusra Khan, Fakhra Bibi, Muhammad Zafa, Humira Huseynova,
Muhammad Rizwan Khan**

ENTOMOPHILOUS FLORA AND INSECT DYNAMICS IN THE ARID ECOSYSTEM OF MIANWALI 11

Nadiia Skobel, Ivan Moysiyenko

OLD CEMETERIES AS REFUGE OF THE STEPPE FLORA IN THE RIGHT-BANK DNIPRO GRASS STEPPE
DISTRICT (SOUTHERN UKRAINE) 24

Safiyakhanim Babanli, Ismat Ahmadov, Rovshan Khalilov

ZNO NANOPARTICLES IMPACT THE PHOTOSYNTHETIC AND ENZYME ACTIVITY OF BARLEY
(HORDEUM VULGARE) PLANTS IN DROUGHT CONDITIONS 43

**Gulzoda Ermatova, Nasibahon Naraliyeva, Gulbahor Ibrohimova, Abdulla Rakhmataliev,
Ziyoviddin Yusupov**

ASSESSING ECOLOGICAL SUITABILITY OF INULA GRANDIS THROUGH CLIMATE MODELING..... 53

Dashgin Ganbarov, Safura Babayeva

THE CURRENT STATUS OF WOODY SPECIES OF THE ROSACEAE JUSS. FAMILY SPREADING
IN THE MOUNTAIN XEROPHYTIC AND STEPPE VEGETATION OF THE JULFA REGION 61

Majnun Babaev, Khatira Mammadova, Majidli Ismail, Ilahiya Huseynova

INVESTIGATION OF THE RESISTANCE OF GRAPE GENOTYPES TO PLASMOPARA VITICOLA PATHOGENS... 67

Khanbala Rustamov, Elchin Hajiyev, Sevda Babayeva

EVALUATION OF GENETIC DIVERSITY WITHIN THE GENE POOL OF POLONICUM WHEAT (TRITICUM
POLONICUM L.) IN AZERBAIJAN 73

Aygun Sardarova

COMPARATIVE ECOLOGICAL ANATOMICAL STUDY OF THE STRUCTURAL ADAPTATION OF THE
MEDICINALLY IMPORTANT PLANT SALVIA NEMOROSA L. UNDER IN SITU AND EX SITU CONDITIONS 81

Kamala Asadova, Rena Abdiyeva, Nigar Mursal, Sadiq Alasqarov

CHARACTERISTICS OF DESERT VEGETATION OF THE COASTAL PART OF SALYAN REGION
(SOUTH-EASTERN PART OF AZERBAIJAN, SHIRVAN LOWLAND) 101

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