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BIOECOLOGICAL CHARACTERISTICS AND EFFICIENT UTILIZATION OF WILD SPECIES OF THE SAINFOIN GENUS (*Onobrychıs* Mill.)

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The increasing risks to food security under climate change conditions make the study of forage crops and their wild relatives an actual scientific issue. In this context, the investigation of wild sainfoin (*Onobrychis* Mill.) species, distinguished by their adaptability to diverse ecological conditions, their role in improving soil fertility, and their efficient use in agriculture, is of particular importance. Azerbaijan is one of the primary centers of diversity of the genus *Onobrychis* and represents a key region for the study of its genetic resources. The main objective of this study is to comprehensively investigate the bioecological characteristics of wild species of the genus *Onobrychis* and to assess their potential for agricultural use. The study is based on 214 samples collected along 40 roads, covering various botanical-geographical regions of Azerbaijan. For each population, a wide range of ecogeographical parameters was recorded, including geographic coordinates, elevation above sea level, slope inclination, annual maximum and minimum temperatures, annual precipitation, relief characteristics, soil texture, humus and organic carbon content, nitrogen level, pH, phosphorus pentoxide (P_2O_5) and magnesium content, as well as habitat type, grazing intensity, and soil erosion degree. Statistical analyses of ecogeographical variables and principal component analysis (PCA) revealed that soil, climate, and relief factors significantly influence species distribution and adaptive traits. According to PCA results, the Component 1 is mainly associated with soil properties and climatic variables, whereas the Component 2 is related to relief and geomorphological factors. The results indicate that some species (*O. caput-galli, O. michauxii, O. buhseana, O. radiata, O. altissima, O. nemecii, O. inermis, O. iberica,* and *O. cyri*) exhibit high tolerance to stress conditions, suggesting their potential use as promising forage crops under climate variability.

Keywords: *Onobrychis, PCA, Azerbaijan, ecogeographical data*

INTRODUCTION

Onobrychis Mill. (sainfoin) is a genus belonging to the tribe *Hedysareae* of the family *Fabaceae*. The genus is represented by more than 150 species worldwide and is mainly distributed in temperate regions of the Northern Hemisphere (Lewis, 2005; Hadadi, 2023). The main centers of genetic diversity of the genus are considered to be the Eastern Mediterranean and Southwest Asia (Тамамшян, 1954; Гроссгейм, 1952). According to recent literature, 28 wild species of this genus have been recorded in Azerbaijan (Azizkhanli, 2023).

Species of the genus *Onobrychis* are annual or perennial herbaceous or semi-shrub plants. Their stems are erect or slightly spreading and branched. Flowers are mostly pink, purple, or light red and are arranged in racemes or panicle-like inflorescences. The fruits are one-seeded pods, often with spiny or tuberculate surfaces. Pollination is mainly entomophilous and occurs especially with the participation of bees (Noori et al., 2014). Morphological characteristics of pods and seeds such as size, shape, color, and the presence of dorsal and ventral grooves play an important role in seed dispersal and taxonomic differentiation (Kahraman et al., 2011).

Species of *Onobrychis* are distinguished by high productivity, nutritional value, and agroecological stability. They are widely known as pasture and hay forage crops as well as

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valuable honey plants (Craine et al., 2023; Исаев, 2023). Being rich nectar sources, sainfoins play an important role in increasing honey production. Although some species are used in folk medicine against diarrhea, they are not among widely used medicinal plants (Kozuharova, 2019). The plants are rich in flavonoids, tannins, and other phenolic compounds, have low toxicity, and are of interest as sources of biologically active substances (Amirahmadi. et al., 2018).

Sainfoin is one of the most valuable forage plants used in feeding ruminant animals. Its high protein content, good palatability, and, most importantly, the absence of bloat formation in the rumen are among its main advantages (Biligetu et al., 2021). In addition, *Onobrychis* species have been shown to reduce the number of nematode parasites in the digestive system of animals (Hoste et al., 2015). Please correct throughout the text

Sainfoin has a strong and deep root system, allowing it to grow well even in arid and semi-arid areas where other forage plants develop poorly. Due to its large taproot, it is resistant to drought stress, increases soil organic matter reserves, and prevents erosion (Beyaz, 2019; Sakhraoui et al., 2024). *Onobrychis* species also grow easily on gravelly and calcareous soils and show high tolerance to soil salinity (Irani et al., 2015; Asma Sakhraoui et al., 2023). Owing to their ability to fix atmospheric nitrogen, they improve soil fertility and are considered ecologically valuable plants (Ţîţei, 2021). Together with other grasses, they form productive phytocenoses and are successfully used in the greening of sloping areas (Shakirov et al., 2012; Gurbanov., 2024).

In Azerbaijan, *Onobrychis transcaucasica* Grossh., *O. arenaria* (Kit.) DC., and *O. viciifolia* Scop. are cultivated for agricultural purposes (Hajiyev, 1969). Species of this genus stand out for their adaptability to diverse ecological conditions, their role in improving soil fertility, and their potential use as promising forage crops under climate change conditions.

The aim of this study is to analyze the bioecological characteristics of *Onobrychis* species distributed in Azerbaijan and to assess their potential for efficient use.

MATERIALS AND METHODS

Between 2013 and 2019–2024, 214 samples belonging to 20 taxa were collected along 40 routes throughout Azerbaijan. Ecogeographical data of the collected species were recorded, and information on collection sites is presented in Table 1. Genbank accession number must be included if applicable The specimens were prepared according to standard herbarium methods and deposited in the Herbarium of the Genetic Resources Institute of MSERA. Soil samples were collected from a depth of 0–20 cm and analyzed in the laboratory of the Institute of Soil Science and Agrochemistry of MSERA. Soil samples were collected from a depth of 0–20 cm and analized in the laboratory of the Institute of Soil Science and AgroChemistry of MSERA.

Ecogeographical data obtained from each population included grazing intensity, degree of soil erosion, geographic coordinates, altitude, slope inclination, annual minimum and maximum temperatures, annual precipitation, relief, soil texture, biotope, humus content, organic carbon (OC), total nitrogen (N%), pH, phosphorus pentoxide ($P_2 O_5$), and magnesium. Climatic data for each collection site were obtained from the Hydrometeorological Forecasting Bureau of the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of Azerbaijan. Ecogeographical data were correlated using Python, and principal component analysis (PCA) was conducted using PAST 4.03 (Hammer, 2001).

Table 1.

List of sampled *Onobrychis* populations

Pop.№	**District**	**Latitude**	**Longitude**	**Date**	**Voucher number**
O. caput-galli					
P1	Agdash	40°43'38.2"	47°26'27.4"	2013	A1-2
P2	Ujar	40°29'41.8"	47°43'57.9"	2022	U1
P3	Goychay	40°39'22.2"	47°39'05.3"	2023	GM1
P4	Ismayilli	40°38'30.3"	47°51'46.2"	2013	A1-6
P5	Sheki	41°20'55.2"	47°06'01.2"	2013	A1-2
O. cornuta					
P6	Nakhchivan Kangarli	39°29'04.6"	45°14'13.6"	2021	NVKl-3
O. michauxii					
P7	Lerik	38°41'33.4"	48°23'55.8"	2019	ST1
P8	Lerik	38°41'33.4"	48°23'55.8"	2019	ST4
P9	Lerik	38°41'05.3"	48°23'00.1"	2018	Z6
O. buhseana					
P10	Lerik	38°39'17.7"	48°22'26.9"	2019	ST2
O. vaginalis					
P11	Absheron	40°21'07.8"	49°47'45.3"	2013	B1-3
P12	Ismayilli	40°46'17.4"	48°05'06.5"	2013	A1-8
P13	Shamakhi	40°40'19.8"	48°29'27.2"	2023	ShI-1
O. radiata					
P14	Shamkir	40°48'56.1"	45°57'39.4"	2013	Y1-3
P15	Shamkir	40°42'38.0"	45°55'02.2"	2013	Sh1-1
P16	Gadabay	40°41'05.6"	45°49'57.8"	2013	G1-2
P17	Goy-gol	40°38'03.0"	46°13'41.8"	2013	X1-2
P18	Fuzuli	39°36'30.1"	47°76'01.2"	2024	FSh
P19	Fuzuli	39°36'09.8"	47°11'43.7"	2024	FQ
P20	Fuzuli	39°35'47.3"	46°58'39.3"	2024	FCh
O. altissima					
P21	Goy-gol	40°28'20.3"	46°20'29.1"	2013	V1-1
P22	Goy-gol	40°27'18.2"	46°20'40.5"	2013	V1-2
P23	Gadabay	40°41'05.6"	45°49'57.8"	2013	G1-2
P24	Masalli	39°02'21.9"	48°47'30.9"	2017	MT3
P25	Lerik	38°40'12.6"	48°22'32.7"	2018	Z1
P26	Nakhchivan Shahbuz	39°32'06.9"	45°47'55.2"	2021	NVSh-4
P27	Gadabay	40°39'36.6"	45°47'55.9"	2022	GH-1
P28	Dashkasan	40°28'48.6"	46°03'20.2"	2013	D1-1
P29	Goy-gol	40°27'30.6"	46°20'49.0"	2022	GH-3
P30	Shamakhi	40°38'58.8"	48°34'06.8"	2023	ShM-23
O. komaovii					
P31	Nakhchivan Kangarli	39°29'04.6"	45°14'13.6"	2021	NVKl-3
O. kachetica					
P32	Gadabay	40°39'36.6"	45°47'55.9"	2022	GH-1
O. nemecii					
P33	Shamkir	40°48'56.1"	45°57'39.4"	2013	Y1-3

O. inermis					
P34	Goy-gol	40°27'18.2"	46°20'40.5"	2020	MG1-3
P35	Sheki	41°20'55.2"	47°06'01.2"	2013	A1-2
O. iberica					
P36	Gadabay	40°41'05.6"	45°49'57.8"	2013	G1-2
P37	Nakhchivan Shahbuz	39°32'14.1"	45°48'01.7"	2021	NVSh-7
P38	Nakhchivan Kangarli	39°30'04.1"	45°14'58.2"	2021	NVKl-4
P39	Fuzuli	39°36'30.1"	47°76'01.2"	2024	FSh
P40	Fuzuli	39°36'09.8"	47°11'43.7"	2024	FQ
O. cyri					
P41	Shamakhi	40°40'19.8"	48°29'27.2"	2023	ShI-1
P42	Sheki	41°15'15.4"	47°12'45.2"	2013	N1-1
P43	Gobustan	40°31'30.3"	48°48'13.2"	2019	Sh1
P44	Guba	41°24'14.9"	48°33'12.0"	2022	QV-1
P45	Shamakhi	40°38'04.0"	48°28'28.6"	2022	ShA-1
P46	Sheki	41°15'42.8"	47°12'45.2"	2013	K1-3
P47	Gadabay	40°37'37.4"	45°48'21.2"	2013	G1-1
P48	Ismayilli	40°46'17.4"	48°05'06.5"	2013	A1-8
P49	Goychay	40°39'22.2"	47°39'05.3"	2023	GM1
P50	Fuzuli	39°36'30.1"	47°76'01.2"	2024	FSh
P51	Shusha	39°45'08.5"	46°45'29.2"	2024	ShC
O. hajastana					
P52	Nakhchivan Kangarli	39°29'44.1"	45°14'16.9"	2021	NVKl-5
O. transcaucasica					
P53	Nakhchivan Shahbuz	39°32'06.9"	45°47'55.2"	2021	NVSh-4
P54	Shusha	39°45'08.5"	46°45'29.2"	2024	ShC
O. cyri* var. *purpurea					
P55	Agdash	40°38'04.5"	47°35'15.7"	2013	A1-5
O. biebersteinii					
P56	Dashkasan	40°28'48.6"	46°03'20.2"	2013	D1-1
P57	Goy-gol	40°27'18.2"	46°20'40.5"	2020	MG1-3
P58	Goy-gol	40°28'20.3"	46°20'29.1"	2020	MG1-2
O. bobrovii					
P59	Goy-gol	40°38'03.0"	46°13'41.8"	2013	X1-2
O. bungei					
P60	Sheki	41°15'42.8"	47°12'45.2"	2013	K1-3
O. arenaria* subsp. *cana					
P61	Goy-gol	40°28'20.3"	46°20'29.1"	2020	MG1-2

RESULTS AND DISCUSSION

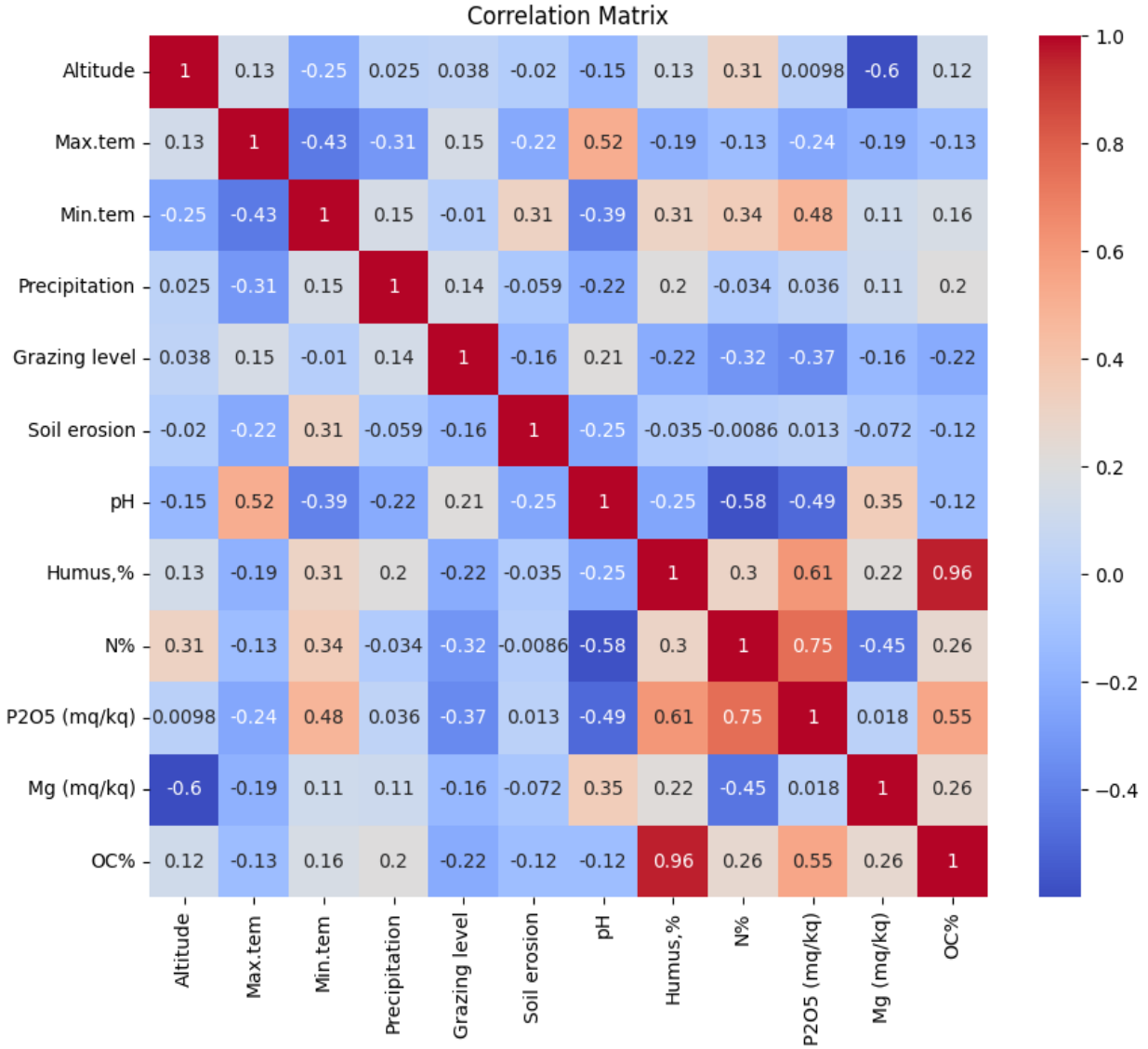


Figure. 1. Correlation of ecogeographical data

Based on correlation analysis, strong correlations were observed between the pairs Humus % – OC % and N % – P_2 O_5 (Figure 1). To reduce the effect of high multicollinearity among variables and to more clearly identify major ecological–soil gradients, only one variable from each highly correlated group was selected, and thus the variables used in the PCA were optimized. This selection facilitated ecological interpretation of PCA results and revealed the core structure of soil–plant relationships. The selected variables represented key ecological components reflecting soil fertility, climatic influences, and anthropogenic management factors: altitude, annual maximum and minimum temperature, annual precipitation, pH, humus, N%, Mg, grazing level, biotope, slope aspect, soil erosion, relief, and soil texture.

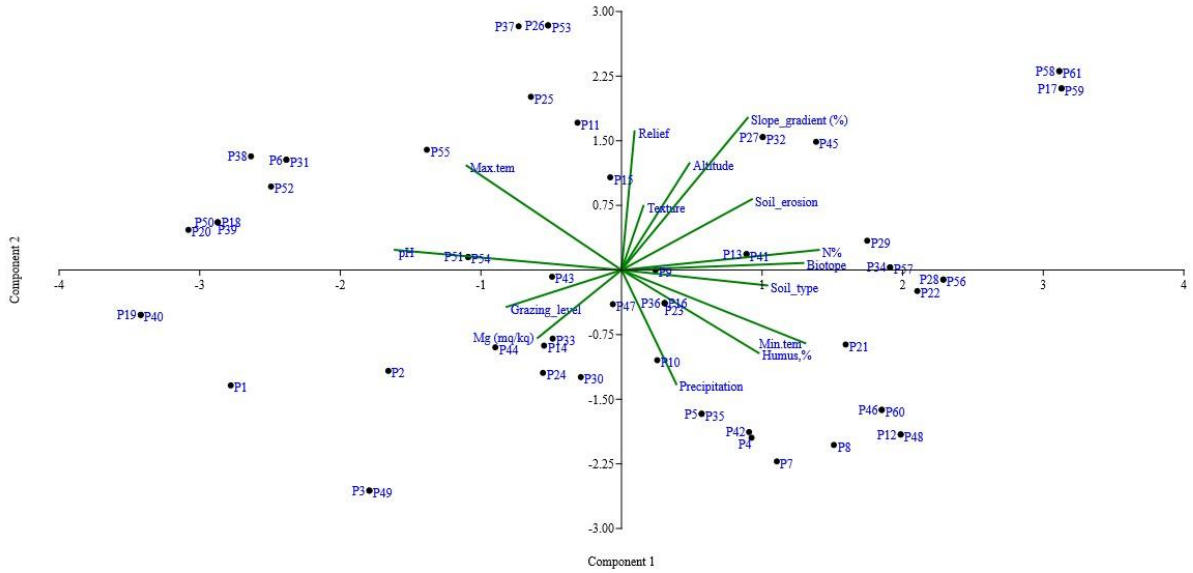


Figure. 2. PCA analysis of species

The first principal component (Component 1) was mainly associated with soil type, biotope, nitrogen content (N%), humus content, minimum temperature, and moisture factors, whereas the second component (Component 2) was related to relief, altitude, slope inclination, soil texture, and degree of soil erosion (Figure 2).

According to PCA distribution, species differed in their ecological requirements and adaptation strategies. *O. vaginalis*, *O. altissima*, *O. cyri*, *O. biebersteinii*, *O. bobrovii*, *O. bungei*, and *O. arenaria* subsp. *cana* were closely associated with soil fertility and moisture factors, while *O. vaginalis*, *O. radiata*, *O. altissima*, *O. komaovii*, *O. kachetica*, *O. iberica*, *O. cyri*, *O. transcaucasica*, and *O. cyri* var. *purpurea* were adapted to relief and altitude factors. *O. caput-galli*, *O. michauxii*, *O. buhseana*, *O. radiata*, *O. altissima*, *O. nemecii*, *O. inermis*, *O. iberica*, and *O. cyri* were distinguished by a wide ecological amplitude and high stress tolerance.

Interpretation of the PCA plot shows that the species occupy different ecological niches and possess high adaptive potential to both climatic and soil factors. Species with positive loadings on Component 1 are associated with soil fertility, moisture, and biotope factors, indicating their agrobiological potential, particularly as forage crops. These species may be considered important genetic resources for increasing productivity in agricultural systems.

Species dominant along Component 2 are distributed in mountainous and foothill regions and show adaptation to slope inclination and soil erosion-related factors. This highlights their potential use in soil conservation, biological erosion control measures, and ecosystem restoration.

Species located near the center of the PCA plot (e.g., *O. cyri*, *O. inermis*, *O. iberica*) exhibit broad ecological plasticity and the ability to adapt to diverse environmental conditions, increasing their strategic importance in introduction, breeding, and adaptive agriculture programs.

CONCLUSION

The results of the study indicate that species of the genus *Onobrychis* differ significantly in their bioecological characteristics, demonstrating a rich genetic potential that ensures adaptation to diverse environmental conditions. The varied responses of species to soil and climatic factors create wide opportunities for their effective use both in natural ecosystem conservation and in

agriculture. Thus, comprehensive ecological assessment of wild *Onobrychis* species is of great scientific and practical importance for biodiversity conservation, sustainable agricultural development, and rational use of natural resources.

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YABANI XAŞA CİNSİ (*Onobrychıs* Mill.) NÖVLƏRİNİN BIOEKOLOJİ XÜSUSİYYƏTLƏRİ VƏ SƏMƏRƏLİ İSTİFADƏSİ

Əzizxanlı Xarıbül
Azərbaycan Respublikası Elm və Təhsil Nazirliyi Genetik Ehtiyatlar İnstitutu

İqlim dəyişikliyi şəraitində qida təhlükəsizliyi risklərinin artması yem bitkilərinin və onların yabanı əcdadlarının öyrənilməsini aktual elmi məsələyə çevirir. Bu baxımdan, müxtəlif ekoloji şəraitə yüksək uyğunlaşma qabiliyyəti, torpaq münbitliyinin artırılmasındakı rolu və kənd təsərrüfatında səmərəli istifadəsi ilə seçilən yabanı xaşa (*Onobrychis* Mill.) növlərinin tədqiqi xüsusi əhəmiyyət kəsb edir. Azərbaycan *Onobrychis* cinsinin əsas müxtəliflik mərkəzlərindən biri olmaqla, bu cinsin genetik ehtiyatlarının öyrənilməsi üçün mühüm ərazidir. Bu tədqiqatın əsas məqsədi *Onobrychis* cinsinə aid yabanı növlərin bioekoloji xüsusiyyətlərini kompleks şəkildə araşdırmaq və onların kənd təsərrüfatında potensial istifadəsini qiymətləndirməkdir. Tədqiqat 40 marşrut üzrə toplanmış 214 nümunəyə əsaslanır və nümunələr Azərbaycanın müxtəlif botanika-coğrafi rayonlarını əhatə edir. Hər bir populyasiya üzrə geniş spektrli ekocoğrafi göstəricilər qeydə alınmışdır: coğrafi koordinatlar, dəniz səviyyəsindən hündürlük, yamacın meyilliliyi, illik maksimum və minimum temperatur, illik yağıntı miqdarı, relyef xüsusiyyətləri, torpağın mexaniki tərkibi, humus və üzvi karbon miqdarı, azot səviyyəsi, pH göstəricisi, fosfor pentaoksid ($P_2 O_5$) və maqnezium miqdarı, həmçinin biotop tipi, otarılma intensivliyi və torpaq eroziyası dərəcəsi. Ekocoğrafi göstəricilər üzrə aparılan statistik analizlər və əsas komponentlər analizi (PCA) nəticələri torpaq, iqlim və relyef amillərinin növlərin yayılmasına və adaptasiya xüsusiyyətlərinə mühüm təsir göstərdiyini müəyyən etmişdir. PCA nəticələrinə görə, Component 1 əsasən torpaq xüsusiyyətləri və iqlim göstəriciləri ilə, Component 2 relyef və geomorfoloji amillərlə əlaqəli olmuşdur. Nəticələr göstərmişdir ki, bəzi növlər (*O. caput-galli, O. michauxii, O. buhseana, O. radiata, O. altissima, O. nemecii, O. inermis, O. iberica* və *O. cyri*) yüksək stress şəraitinə davamlılıq nümayiş etdirir və bu xüsusiyyətlər onların iqlim dəyişkənliyi fonunda perspektivli yem bitkiləri kimi istifadəsini mümkün edir.

Açar sözlər: *Onobrychis, PCA, Azərbaycan, ekocoğrafi məlumatlar*

БИОЭКОЛОГИЧЕСКИЕ ХАРАКТЕРИСТИКИ И ЭФФЕКТИВНОЕ ИСПОЛЬЗОВАНИЕ ДИКИХ ВИДОВ РОДА ЭСПАРЦЕТА (*Onobrychis* Mill.)

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Возрастающие риски для продовольственной безопасности в условиях изменения климата делают изучение кормовых культур и их диких сородичей актуальной научной задачей. В этом

контексте особое значение приобретает исследование диких видов эспарцета (*Onobrychis* Mill.), отличающихся высокой адаптивностью к различным экологическим условиям, важной ролью в повышении плодородия почв и эффективным использованием в сельском хозяйстве. Азербайджан является одним из основных центров разнообразия рода *Onobrychis*, что делает его важным регионом для изучения генетических ресурсов данного рода. Целью данного исследования является изучение биоэкологических характеристик диких видов рода *Onobrychis* и оценка их потенциала для использования в сельском хозяйстве. Исследование основано на 214 образцах, собранных по 40 маршрутам, охватывающим различные ботанико-географические районы Азербайджана. Для каждой популяции были зафиксированы многочисленные экогеографические показатели, включая географические координаты, высоту над уровнем моря, крутизну склонов, годовые максимальные и минимальные температуры, количество осадков, особенности рельефа, механический состав почвы, содержание гумуса и органического углерода, уровень азота, pH, содержание пятиокиси фосфора ($P_2 O_5$) и магния, а также тип биотопа, интенсивность выпаса и степень эрозии почвы. Статистический анализ экогеографических показателей и анализ главных компонент (PCA) показали, что почвенные, климатические и рельефные факторы существенно влияют на распределение видов и их адаптационные особенности. Согласно результатам PCA, Component 1 в основном связан с почвенными и климатическими показателями, тогда как Component 2 отражает влияние рельефных и геоморфологических факторов. Полученные результаты свидетельствуют о том, что некоторые виды (*O. caput-galli, O. michauxii, O. buhseana, O. radiata, O. altissima, O. nemecii, O. inermis, O. iberica* и *O. cyri*) обладают высокой устойчивостью к стрессовым условиям, что позволяет рассматривать их как перспективные кормовые культуры в условиях климатической изменчивости.

Ключевые слова: *Onobrychis, PCA, Азербайджан, экогеографические данные*

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