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INVESTIGATION OF GENETIC DIVERSITY BASED ON PHYSIOLOGICAL INDICATORS IN SOME OAK (*QUERCUS* SSP.) SPECIES

G.N.Aliyeva¹, J.M.Ojaghi², Z.A.Mammadova¹, V.N.Badalova¹,
V.M.Ismayilova¹, M.Y.Hasanova¹

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In view of the ecological importance of forests in combating global warming, there has been increasing attention in recent years to researching Quercus species for their ability to withstand drought. We compared four Quercus species in different sites of Azerbaijan (Gabala, İsmayilli, Shaki, Lankaran, Ganja, Baku). Thus, five functional traits (relative water content (RWC), water content (WC), leaf mass per unit area (LMA), specific leaf area (SLA), and succulence (S)) related to drought tolerance were measured. Based on the results of these functional traits, the Euclidean genetic distance index was determined and cluster analysis was performed. As the temperature increases and the amount of precipitation decreases, plants are exposed to drought stress, which is accompanied by a decrease in RWC, WC, SLA and S. In contrast, an increase in LMA was observed. So, the conducted analyses show that there is significant genetic diversity among oak genotypes and that this diversity is formed under the influence of ecological adaptation, geographical distribution and evolutionary processes.

Keywords: forest, functional traits, drought, Relative Water Content, adaptation ability

Drought and heat have undesirable effects on trees. The most sudden impact of raised temperatures in the atmosphere and increased dryness in the soil is damage to mesophyll and stomatal conductance of leaves, which consequently weaken carbon absorption. Drought also disrupts the water balance in trees, leading to their death. The increasing density and intensity of drought are predicted to contribute to global warming in the future. Heat and drought stresses make plants more liable to other abiotic stress factors. Therefore, increased sensitivity leads to higher tree mortality, increased wildfire risk, and a decline in biodiversity among plants and animals. Such conditions also change phenology and plant evolution, causing turbulence effects on the ecosystem. The spatial extent and severity of drought events vary, and their impacts depend on local ecological characteristics of the forests, species-specific temperature and moisture thresholds that limit tree functioning, and adaptation strategies and acclimation of tre-

es to more frequent and intense extreme conditions [1, 3].

The considering of ecological significance of forests in struggling global warming in future increase attention to studying. *Quercus* acts as a dominant genus in a large part of the forests of Azerbaijan. *Quercus* has high economic significance and rich resources in Azerbaijan. The depiction of oak leaves on the national emblem of Azerbaijan emphasizes its importance for Azerbaijani nature. The oak tree plays an important role in soil and water protection and ecological balance. The bark of oak trees can be used for extracting tannins, and the leaves can be used to support sericulture [5, 8].

Leaves exhibited different morphological and functional traits in different climates and environmental conditions. They are sensitive to changes in environmental conditions (air pollution, soil conditions, drought, direction of wind, temperature, etc.). By monitoring plant functions, changes in environmental conditions can

be detected at an early stage, and the influence of climate change on biotic systems can be assessed. Studying these differences helps us understand how plants adapt to their environments. RWC estimating the degree of water stress caused by drought can be physiologically quantified by either the leaf water potential or the relative leaf area. The morphological features (specific leaf area, leaf thickness and stomatal density) and physiological traits (RWC, WC, S, antioxidant system and osmotic solutes) of leaves are usually used as important indicators in drought research [2, 3, 4].

Specifically, the given paper aimed to evaluate the response and adaptation ability of oak trees to different ecological conditions, analyze functional traits and to determine the genetic affinity of the studied samples by these traits. Then cluster analysis based on these functional traits was conducted and the Euclidean genetic distance index was determined.

Materials and methods

The studied oak species (*Quercus petraea* ssp. *iberica* (Stev.) – Georgian oak – from Ismayilli, Gabala, Shaki, and Baku;

Quercus macranthera ssp. *macranthera* (K.Koch) Menitsky – Eastern oak – from Goygol and Sheki; *Quercus castaneifolia* C.A.Mey – Chestnut-leaved oak – from Baku and Lankaran; *Quercus robur* ssp. *pedunculiflora* (K.Koch) – Pedunculate oak – from Gabala and Baku) were selected from ecologically diverse regions of the Republic (Table 1) [6].

Five functional traits related to drought resistance were measured: relative water content (RWC), water content (WC), leaf mass per area (LMA), specific leaf area (SLA), and succulence (S). For this purpose, leaf samples were randomly collected from mature trees. Leaf area was measured using a CI-202 LEAF AREA METER (USA). Then, the leaves were weighed using an electronic scale (EK-610i) with 0.01 g precision. Fresh mass (FM) (immediately after being collected from the tree), turgid mass (TM) (after being stored in water in the dark in a refrigerator for 24 hours), and dry mass (DM) (after being dried in a thermostat at 70°C for 72 hours) were recorded [2].

Table 1

Ecological features of study areas [6]

Locality	Study area	Coordinate	Altitude (m)	Substrate
Shaki	Kish	41° 11' 31" N 47° 10' 14" E	636	mountain-forest brown, typical
Gabala	Little Pirali	40°58'53"N 47°50'45"E	900	mountain-forest brown, typical
İsmayılı	Basgal	40°47'24"N 48°09'07"E	500-800	flood-plain alluvial meadow
Goygol	Goygol National Park	40°58'95" N 46°32'71" E	2470	mountain-gray-cinnamon dark
Lankaran	Hirkan National Park	38°45'13"N 48°51'04" E	1280	yellow-podzol-gley
Baku	Botanical garden	40°23'43"N 49°52'56"E	-28	partially alkaline and salty

Leaf mass per area (LMA, mg cm⁻²), water content (WC), relative water content (RWC), and succulence (S, mg cm⁻²) were calculated using the method of Busotti [2]:

$$LMA = \frac{DM}{SLA}$$

$$WC = \left[1 - \left(\frac{DM}{FM} \right) \right] * 100\%$$

$$RWC = \left[(FM - DM) / (TM - DM) \right] * 100\%$$

$$S = (FM - DM) / SLA$$

Subsequently, based on the results of these functional traits, the Euclidean genetic distance index was determined and cluster analysis was performed.

Results and discussions

Although the physiological parameters of oak leaves from various regions of Azerbaijan

have been studied by us, their genetic similarity based on these indicators has not been analyzed, and cluster analysis has not been performed.

In order to investigate drought resistance in oaks, the results of the analyzed physiological traits are presented in Table 2. The highest values of relative water content (RWC: 86.45±9.81%), water content (WC: 65.60±6.32%), leaf mass per area (LMA: 7.55±1.52 g), specific leaf area (SLA: 98.27±12.30 cm²), and succulence (S: 8.38±0.89 mg·cm⁻²) were recorded in Georgian oak from the Kish population in Shaki. The lowest values of the studied physiological traits (except for LMA) were observed in pedunculate oak from the Botanical Garden population in Baku. Here, RWC was 45.75±15.24%, WC was 16.43±9.67%, LMA was 12.48±6.24 g, SLA was 48.87±16.45 cm², and S was 2.45±1.23 mg·cm⁻².

Table 2

Foliar moisture parameters of studied *Quercus* species under different ecological conditions: (RWC- Relative Water Content, WC- Water Content, LMA- Leaf Mass Per Area, SLA-Specific Leaf Area, S- Succulence, ±standard deviation)

	RWC	WC	LMA	SLA	S
Georgian oak (Ismayilli)	83.38±10.23	54.26±1.45	6.81±0.92	92.23±15.23	8.08±1.32
Georgian oak (Gabala)	84.15±9.52	62.23±6.23	7.16±1.35	67.26±11.21	8.24±0.95
Georgian oak (Shaki)	86.45±9.81	65.60±6.32	7.55±1.52	98.27±12.30	8.38±0.89
Georgian oak (Baku)	37.46±10.36	8.41±2.31	1.46±0.90	42.23±9.32	6.13±1.25
Chestnut-leaved oak (Baku)	70.39±9.85	40.32±9.01	3.77±1.21	69.1±5.98	5.85±1.30
Chestnut-leaved oak (Lankaran)	71.39±8.15	58.03±8.96	7.42±2.01	55.66±4.25	7.79±1.23
Oriental oak (Goygol)	72.54±8.60	52.38±7.16	6.44±1.62	78.1±11.23	7.09±1.56
Oriental oak (Shaki)	85.65±11.23	56.23±8.21	6.35±1.42	80.5±12.60	6.52±0.95
Pedunculate oak (Gabala)	72.54±7.52	52.38±8.16	6.44±1.35	78.1±9.63	7.09±0.92
Pedunculate oak (Baku)	45.75±5.26	16.43±3.59	12.48±2.48	48.87±6.35	2.45±0.96

These results indicate that the pedunculate oak in Baku experienced severe drought stress. RWC values between 50–60% indicate significant water deficiency. In such conditions, many plant functions are disrupted, and cellular damage can occur [1]. The lowest LMA value was recorded in the chestnut-leaved oak population from Baku.

Climate is one of the primary abiotic factors affecting natural systems. Differences in physiological traits and correlations between traits and environment indicate the species' ability to adapt to specific ecological conditions. According to other studies, water is a major factor influencing leaf size, although it is considered less critical compared to temperature. These analyses showed that a reduction in leaf area is a physiologically meaningful response to drought stress in forested areas; such traits are key factors in enabling oak trees to cope with varying moisture conditions. Leaf mass per area reflects the correlation between leaf area and leaf biomass. A negative correlation exists between LMA and SLA. Heavier leaves provide the plant with protection against physical damage and stress. At the same time, higher LMA supports lower transpiration and water loss, contributing to a more efficient photosynthetic rate under drought conditions [4, 7, 9].

CLUSTER ANALYSIS. All studied *Quercus* samples were divided into four main groups based on the Euclidean genetic distance index as a result of cluster analysis (Figure 1, Table 3). The first cluster contained only the Georgian oak (Baku) sample. This result indicates that the corresponding genotype is significantly distant from other oak genotypes in terms of genetic similarity. In other words, the Georgian oak (Baku) genotype possesses distinct genetic characteristics compared to other oak samples. The second cluster, which formed the largest group, included the following oak genotypes: Chestnut-leaved oak (Baku), Eastern oak (Goygol), Pedunculate oak (Qabala),

Eastern oak (Shaki), Pedunculate oak (Baku), and Chestnut-leaved oak (Lankaran). Several interesting observations were recorded in this cluster. No genetic distance ($GD = 0$) was identified between the genotypes of Eastern oak (Goygol) and Pedunculate oak (Qabala), as well as between Eastern oak (Shaki) and Pedunculate oak (Baku). This fact indicates that these genotypes are completely identical. The maximum genetic distance within this cluster was recorded between the Chestnut-leaved oak (Lankaran) and the other two genotypes - Pedunculate oak (Baku) and Eastern oak (Shaki) - with a distance of $GD=28.74$. The third cluster included the Georgian oak (Qabala) and Georgian oak (Shaki) genotypes. The genetic distance identified between these two genotypes was $GD = 41.51$. The fourth cluster consisted solely of the Georgian oak (Ismayilli) genotype. This fact proves that this genotype is quite different from other oak samples in terms of genetic distance.

Overall, the greatest genetic distance among all oak genotypes was observed between Georgian oak (Ismayilli) and Eastern oak (Shaki)- $GD=99.37$, as well as between Georgian oak (Ismayilli) and Pedunculate oak (Baku)- $GD=99.37$. A high genetic distance was also recorded between Georgian oak (Ismayilli) and Chestnut-leaved oak (Lankaran) genotypes- $GD=98.56$. These results show that the Georgian oak (Ismayilli) is the most genetically distinct sample among all oak genotypes and that its genetic characteristics differ sharply from other oak species.

In general, the analyses conducted demonstrate significant genetic diversity among oak genotypes, which appears to be shaped by ecological adaptation, geographical distribution, and evolutionary processes. These findings provide an important scientific basis for the conservation of oak genetic resources and the development of future breeding programs.

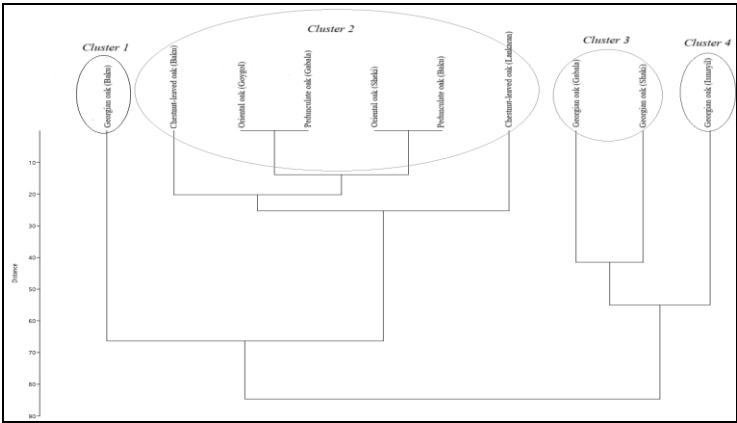


Fig.1. Cluster analysis. *Q.petraea* ssp. *iberica* (Stev.)- Georgian oak, *Q.macranthera* ssp. *macranthera* (K.Koch) Menitsky-Oriental oak, *Quercus castaneifolia* C.A.Mey.- Chestnut-leaved oak, *Quercus robur* ssp. *pedunculiflora* (K.Koch) Menitsky-Pedunculate oak

Table 3

Euclidean genetic distance between studied oak genotypes

	Georgian oak (Ismayilli)	Georgian oak (Gabala)	Georgian oak (Shaki)	Georgian oak (Baku)	Chestnut-leaved oak (Baku)	Chestnut-leaved oak Lankaran	Oriental oak Goygol	Oriental oak (Shaki)	Pedunculate oak (Gabala)	Pedunculate oak (Baku)
Georgian oak Ismayilli)	0	59.3614	50.6534	96.4661	96.7313	98.5565	93.5333	99.3714	93,5333	99,3714
Georgian oak (Gabala)		0	41.5175	64.6736	66.7491	62.0626	63.0100	62.4784	63.01006	62,47841
Georgian oak (Shaki)			0	95.8964	98.1409	98.1263	91.8004	90.3144	91.80043	90.3144
Georgian oak (Baku)				0	56.9019	63.30801	67.8022	71.1028	67.80224	71.10284
Chestnut-leaved oak (Baku)					0	22.63545	15.4833	24.9611	15.4833	24.96119
Chestnut-leaved oak (Lankaran)						0	23.2001	28.7466	23.20019	28.74667
Oriental oak (Goygol)							0	13.8848	0	13.8848
Oriental oak (Shaki)								0	13.8848	0
Pedunculate oak (Gabala)									0	13.8848
Pedunculate oak (Baku)										0

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¹Ministry of Science and Education of the Republic of Azerbaijan,
Institut of Dendrology Azerbaijan
bio890@mail.ru
²Khazar University
javid_804@yandex.ru

BƏZİ PALID (*QUERCUS* SPP.) NÖVLƏRİNDƏ YARPAĞIN FİZİOLOJİ GÖSTƏRİCİLƏRİNƏ ƏSASƏN GENETİK MƏSAFƏNİN TƏYİNİ

G.N.Əliyeva, C.M.Ocaqi, Z.Ə.Məmmədova, V.N.Bədəlova, V.M.İsmayılova, M.Y.Həsənova

Global istiləşmə ilə mübarizədə meşələrin ekoloji əhəmiyyətini nəzərə alaraq, son illərdə *Quercus* növlərinin quraqlığa davamlılığının tədqiqi diqqət mərkəzindədir. Tədqiqat obyektı olan palıd növləri (*Quercus petraea* ssp. *iberica* (Stev.), *Quercus macranthera* ssp. *macranthera* (K.Koch) Menitsky, *Quercus castaneifolia* C.A.Mey., *Quercus robur* ssp. *pedunculiflora* (K.Koch)) respublikamızın müxtəlif ərazilərində (Qəbələ, İsmayıllı, Şəki, Lənkəran, Gəncə, Bakı) müqayisəli şəkildə tədqiq edilmişdir. Quraqlığa davamlılıqla əlaqəli beş funksional əlamət (nisbi su tutumu (NST), su tutumu (ST), vahid sahəyə görə yarpaq kütləsi (YK), spesifik yarpaq sahəsi (YS) və şirəlilik (Ş)) ölçülmüşdür. Bu funksional əlamətlərin nəticəsi əsasında Evklid genetik məsafə indeksi müəyyən edilmiş və klaster analizi aparılmışdır. Temperatur artdıqca və yağıntının miqdarı azaldıqca NST, ST, YS və Ş-nin azalması, YK-nin artması müşahidə olunmuşdur. Aparılan tədqiqatlar palıd genotipləri arasında əhəmiyyətli genetik müxtəlifliyin olduğunu və bu müxtəlifliyin ekoloji uyğunlaşma, coğrafi yayılma və təkamül proseslərinin təsiri altında formalaşdığını göstərir.

Açar sözlər: meşə, quraqlıq, nisbi su tutumu, su tutumu, Cluster analiz

ИССЛЕДОВАНИЕ ГЕНЕТИЧЕСКОГО РАЗНООБРАЗИЯ НА ОСНОВЕ ФИЗИОЛОГИЧЕСКИХ ПОКАЗАТЕЛЕЙ У НЕКОТОРЫХ ВИДОВ ДУБА (*QUERCUS* SPP.)

Г.Н.Алиева, Дж.М.Оджаги, З.А.Маммадова, В.Н.Бадалова, В.М.Исмаилова, М.Ю.Гасанова

Учитывая экологическую важность лесов в борьбе с глобальным потеплением, в последние годы увеличилось внимание к исследованию видов дуба (*Quercus*) на их способность противостоять засухе. Мы сравнили четыре вида дуба в различных районах Азербайджана (Габала, Исмаиллы, Шеки, Ленкорань, Гянджа, Баку). Таким образом, были измерены пять функциональных признаков, связанных с устойчивостью к засухе: относительное водосодержание (RWC), водосодержание (WC), масса листа на единицу площади (LMA), удельная площадь листа (SLA) и суккулентность (S). На основе результатов этих функциональных признаков был определен индекс евклидова генетического расстояния и проведен кластерный анализ. С повышением температуры и уменьшением количества осадков растения подвергаются стрессу от засухи, что сопровождается снижением показателей RWC, WC, SLA и S. Напротив, наблюдается увеличение LMA. Проведенный анализ показывает, что существует значительное генетическое разнообразие среди генотипов дуба, и это разнообразие формируется под влиянием экологической адаптации, географического распределения и эволюционных процессов.

Ключевые слова: *Quercus*, лес, функциональные признаки, засуха, относительное водосодержание, адаптационные способности