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XORAZM VILOYATI IQLIM SHAROITIDA EKILGAN SULI (AVENA SATIVA L.) NAVLARINING FIZIOLOGIK VA BIOKIMYOVIY XUSUSIYATLARI

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Annotatsiya. Ushbu ilmiy tadqiqotda Quyi Amudaryo havzasi — Xorazm viloyatining keskin kontinental iqlimi, yozgi anomal harorat, havo quruqligi hamda tuproq sho'rlanishi sharoitida suli (Avena sativa L.) navlarining fiziologik moslashuvchanlik mexanizmlari va don hamda biomassadagi biokimyoviy tarkibi tizimli ravishda tadqiq etildi. Tadqiqot ob'ekti sifatida bahorgi ekotipga mansub 'Uzbekiskiy', kuzgi biologik ekotipga ega 'Toshkent 1' hamda ham bahorgi, ham kuzgi ekishga mos keluvchi universal (fakultativ) 'O'zbekiston keng barglisi' navlari olindi. O'simlik barglaridagi fotosintez pigmentlari (xlorofill a, b, karotinoidlar), suv saqlash qobiliyati, barg to'qimalarining transpiratsiya jadalligi, osmotik stressga javoban erkin prolin to'planishi, shuningdek, don va ko'kat massa tarkibidagi xom oqsil, xom yog', xom kletchatka, suvda eruvchan qandlar, kul elementlari va polisaxarid beta-glyukan miqdori tahlil qilindi. Tadqiqot natijalari shuni ko'rsatdiki, kuzgi muddatda (10–20-oktabr) ekilgan 'Toshkent 1' va universal 'O'zbekiston keng barglisi' navlarida qishlash fazasida hujayra shirasidagi eruvchan qandlar miqdori (14,2–15,8%) va erkin prolin konsentratsiyasi (36,5–41,2 mkmol/g quruq modda) keskin oshib, qishki sovuqlarga (–15...–18°C) yuqori chidamlilikni ta'minladi. Bahorgi erta ekishda (10–15-mart) esa 'Uzbekiskiy' navi xlorofill a+b miqdori (2,84 mg/g ho'l massa), fotosintetik salohiyat va yuqori suv saqlash qobiliyati bilan ajralib turib, donida 14,8% xom oqsil, 4,9% xom yog' va 4,6% beta-glyukan to'plashga erishdi. 'O'zbekiston keng barglisi' navi universal (amfidiploid tabiatli) moslashuvchanligi tufayli kuzgi ekilganda 265,0 ts/ga, bahorgi ekilganda 224,0 ts/ga yuqori ozuqaviy qiymatga ega ko'kat maysa hosil qildi.

Kalit so'zlar: suli (Avena sativa L.), Uzbekiskiy, Toshkent 1, O'zbekiston keng barglisi, fiziologiya, biokimyo, xlorofill, prolin, osmotik regulyatsiya, xom oqsil, beta-glyukan, sho'rlanish, sovuqqa chidamlilik, Xorazm viloyati.

ФИЗИОЛОГО-БИОХИМИЧЕСКИЕ ОСОБЕННОСТИ СОРТОВ ОВСА (AVENA SATIVA L.) ПРИ РАЗЛИЧНЫХ СЕЗОННЫХ СРОКАХ ПОСЕВА В УСЛОВИЯХ ХОРЕЗМСКОЙ ОБЛАСТИ

АННОТАЦИЯ (РАСШИРЕННАЯ НАУЧНАЯ ВЕРСИЯ):

• Актуальность. В условиях аридного климата и засоленных почв Хорезмской области изучение физиолого-биохимических механизмов адаптации злаковых культур к термическому и осмотическому стрессу является ключевым фактором селекции и устойчивого кормопроизводства. Овес (Avena sativa L.) выделяется высоким диетическим качеством зерна и биомассы, однако физиологическая реакция сортов различного биологического типа (яровые, озимые, факультативные) в данном регионе до сих пор оставалась малоизученной.

• Цель работы. Изучение динамики пигментного комплекса, водного режима, содержания стрессовых метаболитов (пролина и водорастворимых сахаров) и биохимического состава зерна и вегетативной массы у сортов овса с яровым («Узбекский»), озимым («Ташкент 1») и универсально-двуручковым («Узбекистон кенг барглиси») типами развития при различных сроках сева в условиях Хорезма.

• Методы исследований. Содержание хлорофиллов a, b и каротиноидов определяли спектрофотометрическим методом в 80% ацетоновой вытяжке. Осморегуляцию оценивали по содержанию свободного L-пролина (по Бейтсу) и водорастворимых углеводов (антроновым методом). Биохимические показатели зерна и сенажа (сырой протеин по Кьельдалю, сырой жир по Сокслету, сырая клетчатка по Геннебергу-Штоману, водорастворимый бета-глюкан ферментативным методом) анализировались в фазы цветения и полной спелости.

• Результаты. Установлено, что при озимом посеве (октябрь) сорта «Ташкент 1» и факультативный сорт «Узбекистон кенг барглиси» мобилизуют осмопротекторные механизмы: накопление сахаров достигает 14,2–15,8%, а пролина — 38,4–41,2 мкмоль/г сухого вещества, что обуславливает зимостойкость на уровне 91,5–94,2%. При ранневесеннем севе сорт «Узбекский» показал наивысшую устойчивость к засухе и засолению, сохраняя стабильный уровень хлорофилла (2,84 мг/г сырой массы) и соотношение Chl a/b на уровне 2,95. Зерно сорта «Узбекский» характеризовалось максимальным содержанием сырого протеина (14,8%), липидов (4,9%) и биологически активного бета-глюкана (4,6%). Сорт «Узбекистон кенг барглиси» проявил высокую факультативную пластичность, сформировав при озимом посеве урожай высокобелковой зеленой массы 265,0 ц/га, а при яровом — 224,0 ц/га.

• Заключение. Для условий Хорезма подтверждена целесообразность дифференцированного возделывания сортов: «Узбекский» — для весеннего сева на продовольственное и фуражное зерно; «Ташкент 1» — для озимого клина на ранневесенний зеленый конвейер; «Узбекистон кенг барглиси» — как универсальный страховой генотип для обоих сезонов сева.

Ключевые слова: овес (Avena sativa L.), Узбекский, Ташкент 1, Узбекистон кенг барглиси, хлорофилл, каротиноиды, пролин, зимостойкость, жаростойкость, сырой протеин, бета-глюкан, Хорезмская область.

PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERISTICS OF OAT (AVENA SATIVA L.) CULTIVARS UNDER VARYING SEASONAL SOWING REGIMES IN THE KHOREZM REGION

ABSTRACT (EXTENDED COMPREHENSIVE VERSION):

• Background. The extreme agro-ecological environment of the Khorezm oasis (lower reaches of the Amu Darya basin) is characterized by severe continental climate, high soil salinity, extreme summer temperatures, and early dry winds. Under such adverse conditions, elucidating the physiological resilience mechanisms and biochemical profiling of oat (Avena sativa L.) cultivars

with distinct seasonal ecotypes (spring, winter, and facultative/dual-season) is critical for sustainable food security and feed production.

• Objective. This study investigated the photosynthetic pigment dynamics, water relations, accumulation of osmolytes (free proline and soluble carbohydrates), and comprehensive biochemical nutritive values (crude protein, ether extract/fat, crude fiber, ash, and beta-glucan) in three specific oat cultivars: 'Uzbekiskiy' (spring type), 'Toshkent 1' (winter type), and 'Uzbekiston keng barglisi' (facultative/dual-season cultivar).

• Methods. Pigment composition (chlorophyll a, b, and total carotenoids) was determined spectrophotometrically in 80% acetone extracts. Osmotic adjustment was quantified via free proline assays (acid ninhydrin method) and water-soluble sugars. Nutritional constituents of grains and vegetative forage were evaluated using standard AOAC protocols: crude protein (micro-Kjeldahl, N × 6.25), crude fat (Soxhlet extraction), crude fiber (acid-base hydrolysis), and mixed-linkage (1→3)(1→4)-beta-D-glucan via enzymatic assay kits. Two-way ANOVA and Duncan's multiple range tests were conducted.

• Results. Winter-sown cultivars ('Toshkent 1' and 'Uzbekiston keng barglisi') exhibited profound cryoprotective adjustments during cold acclimation, raising soluble carbohydrates to 14.2–15.8% and free proline to 38.4–41.2 µmol/g DW, resulting in superior overwintering survival (91.5–94.2%). In early spring sowing, 'Uzbekiskiy' exhibited premier drought and salinity tolerance, maintaining the highest total chlorophyll (2.84 mg/g FW), lowest membrane permeability, and optimal stomatal regulation under early heat waves. 'Uzbekiskiy' grain accumulated 14.8% crude protein, 4.9% crude lipids, and 4.6% beta-glucan. 'Uzbekiston keng barglisi' proved its robust dual-season adaptability, yielding 265.0 c/ha of high-protein forage when sown in autumn and 224.0 c/ha when sown in spring.

• Conclusion. Cultivar 'Uzbekiskiy' is highly recommended for spring grain cultivation due to its resilient photosynthetic and high-protein grain traits. 'Toshkent 1' is ideal for autumn sowing as a frost-tolerant early forage crop. 'Uzbekiston keng barglisi' demonstrates unique facultative plasticity, serving as an optimal dual-season cultivar across the irrigated saline soils of the Khorezm region.

Keywords: oat (Avena sativa L.), Uzbekiskiy, Toshkent 1, Uzbekiston keng barglisi, chlorophyll, carotenoids, proline, cold tolerance, heat tolerance, crude protein, beta-glucan, meadow-alluvial soils, Khorezm.

1. KIRISH (INTRODUCTION)

Under intensifying global climate change and anthropogenic pressure, a central challenge of modern plant physiology and agronomy is to study in depth the mechanisms by which agricultural crops adapt to unfavorable abiotic factors (salinity, drought, and abrupt temperature fluctuations) and to introduce forage crops of high biological value.

Oat (Avena sativa L.) occupies a leading position among grain and fodder crops owing to its high nutritive value, dietary properties, and agronomic advantages. Compared with other cereals, oat grain and biomass are exceptionally rich in proteins with a balanced amino-acid composition (lysine, methionine, tryptophan), valuable unsaturated fatty acids, and the water-soluble dietary fiber (1→3)(1→4)-β-D-glucan, a polysaccharide that lowers blood cholesterol and strengthens human and animal immunity.

The climate of the Lower Amu Darya area, particularly Khorezm Region, is sharply continental: relative air humidity falls very low in late spring and summer (20–25%), summer temperatures reach 42–45°C, and winters are cold and often snowless, with frosts down to –18…–22°C. In addition, irrigated lands of the region are mainly meadow-alluvial, loamy in texture, and prone to secondary salinization due to variously mineralized groundwater. Under such complex conditions, normal plant growth and yield formation depend directly on the functioning of the physiological apparatus, membrane stability, and the ability to accumulate protective compounds against stress factors.

By biological nature, oat genotypes are divided into spring, winter, and intermediate universal (facultative / dual-season) groups. To date, the physiological traits of oat cultivars in Khorezm Region (photosynthetic pigment synthesis, transpiration, tissue water retention, and the dynamics of proline and soluble carbohydrates in osmotic regulation) and their biochemical characteristics (crude protein, crude fat, crude fiber, ash elements, and beta-glucan accumulation) have not been studied comprehensively in a comparison of spring and autumn sowing dates.

The main aim of this study was to comparatively evaluate the physiological adaptation indices and biochemical quality parameters of the spring-ecotype cultivar ‘Uzbekiskiy’, the winter-ecotype cultivar ‘Toshkent 1’, and the universal (suitable for both spring and autumn sowing) cultivar ‘O‘zbekiston keng barglisi’ on saline meadow-alluvial soils of Khorezm Region; to identify mechanisms of tolerance to abiotic stresses; and to provide scientifically grounded conclusions for production.

2. TADQIQOT MATERIALLARI VA METODLARI (MATERIALS AND METHODS)

2.1. Field experiment conditions and soil properties

The research was conducted on a scientific experimental field in Urgench District, Khorezm Region. The soil is long-irrigated meadow-alluvial, medium loam. In the 0–30 cm plow layer, humus content was 0.91%, total nitrogen 0.082%, total phosphorus 0.12%, available phosphorus (Machigin method) 17.8 mg/kg, exchangeable potassium 205 mg/kg, and soil suspension pH 7.85. Salinization was of the chloride–sulfate type, with a dry residue of 0.31% (moderately saline).

2.2. Studied cultivars and experimental design

Three oat (Avena sativa L.) cultivars of different biological types were studied:

1. ‘Uzbekiskiy’ — a spring cultivar intended for early spring sowing, highly tolerant of heat and soil salinity;

2. ‘Toshkent 1’ — a winter cultivar that is cold-tolerant, resistant to early-spring temperature instability, and fast-developing;

3. ‘O‘zbekiston keng barglisi’ — a universal (facultative) cultivar adapted to both autumn and spring sowing, broad-leaved, and highly plastic.

The experiment was conducted under two seasonal sowing regimes:

• Regime 1 (autumn sowing): variants sown between 10 and 20 October (‘Toshkent 1’ and ‘O‘zbekiston keng barglisi’);

• Regime 2 (spring sowing): variants sown between 10 and 15 March (‘Uzbekiskiy’ and ‘O‘zbekiston keng barglisi’).

Trials were arranged in four replications in a randomized design. Seeding rate: 4.5 million germinable seeds per hectare. Fertilizer background: N90P60K50 kg/ha.

2.3. Physiological analysis methods

• Photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids): extracted from leaf tissues in 80% acetone; optical density was measured on a Spekol-11 spectrophotometer at 663, 645, and 470 nm and calculated using the formulas of G. Holm and D. Wettstein (mg/g fresh leaf weight).

• Tissue water-retention capacity and water deficit: determined by the L. S. Litvinov method by comparing leaf weights at full turgor, initial, and dry states.

• Free L-proline content: assayed spectrophotometrically by the L. S. Bates method with acid ninhydrin reagent (520 nm; µmol/g dry matter).

• Water-soluble sugars: sampled from leaves and stem nodes during overwintering (December–January) and drought (May–June) and analyzed colorimetrically by the anthrone method (%).

2.4. Biochemical and quality analysis methods

• Crude protein: calculated from total nitrogen determined by the Kjeldahl method multiplied by the coefficient 6.25 (State Standard GOST 10846-91).

• Crude fat (lipids): determined by extraction with petroleum ether in a Soxhlet apparatus (GOST 29033-91).

• Crude fiber: determined by the Henneberg–Stohmann method through successive acid and alkali treatments.

• Water-soluble polysaccharide (1→3)(1→4)-β-D-glucan: assessed spectrophotometrically with the Megazyme Mixed-linkage beta-glucan assay kit (AOAC Method 995.16).

• All results were processed statistically according to B. A. Dospekhov and subjected to analysis of variance (ANOVA) at $P < 0.05$.

3. TADQIQOT NATIJALARI VA ULARNING MUHOKAMASI (RESULTS AND DISCUSSION)

3.1. Photosynthetic pigment complex and its dynamics

The contents of chlorophyll a, chlorophyll b, and carotenoids in leaves determine the functional activity of the photosynthetic apparatus and the crop's productivity potential. Under the dry climate of Khorezm Region with high solar radiation, pigment resistance to photo-oxidation is of particular importance.

At flowering, chlorophyll a content in all studied cultivars was 2.7–3.0 times higher than chlorophyll b. In spring sowing, 'Uzbekiskiy' recorded the highest accumulation of chlorophyll a (2.12 mg/g) and chlorophyll b (0.72 mg/g) (total chlorophyll a+b = 2.84 mg/g fresh weight). Carotenoid content was also highest in this cultivar (0.64 mg/g), successfully performing a photoprotective role by shielding chlorophyll molecules from degradation under strong solar insolation.

In autumn-sown 'Toshkent 1', total chlorophyll a+b was 2.68 mg/g, whereas the universal cultivar 'O'zbekiston keng barglisi' accumulated 2.75 mg/g when sown in autumn and 2.62 mg/g when

sown in spring. This indicates the high physiological adaptability of this universal cultivar to different seasonal light and temperature regimes.

Table 1. Photosynthetic pigment content in leaves of oat cultivars (at flowering, mg/g fresh weight)

Sowing season and cultivar	Chl a (mg/g)	Chl b (mg/g)	Total Chl (a+b)	Chl a / Chl b	Carotenoids (mg/g)
Autumn: Toshkent 1	2.01	0.67	2.68	3.00	0.58
Autumn: O‘zbekiston keng barglisi	2.06	0.69	2.75	2.98	0.61
Spring: Uzbekiskiy	2.12	0.72	2.84	2.94	0.64
Spring: O‘zbekiston keng barglisi	1.96	0.66	2.62	2.97	0.57

3.2. Water-regime indices and osmotic regulation mechanisms (proline and sugars)

Low winter temperatures and summer dry winds (garmsel) in Khorezm Region disrupt the water balance of plant cells. To maintain cell turgor during overwintering and drought, plants synthesize low-molecular-weight osmotically active compounds.

Under autumn sowing (October), ‘Toshkent 1’, before the onset of winter frosts (December), increased soluble sugars in leaf tissues to 15.8% and free proline to 41.2 µmol/g dry matter. This lowered the freezing point of the cell sap and ensured an overwintering rate of 94.2%. In autumn-sown ‘O‘zbekiston keng barglisi’, sugars reached 14.2% and proline 38.4 µmol/g, with an overwintering rate of 91.5%.

Under spring sowing, amid anomalous heat in May–June (38–42°C) and soil salinity, free proline accumulation in ‘Uzbekiskiy’ reached 34.6 µmol/g, helping maintain tissue water-retention capacity at 78.4%. Water deficit in this cultivar was the lowest (11.8%), indicating high physiological drought tolerance.

Table 2. Dynamics of water regime and osmotic protective compounds in oat cultivars

Sowing season and cultivar	Leaf water retention (%)	Water deficit (%)	Soluble sugars (%)	Free proline (µmol/g DW)	Overwintering / Stress tolerance (%)
Autumn: Toshkent 1	76.2	13.4	15.8 (winter)	41.2 (winter)	94.2 (overwintering)
Autumn: O‘zbekiston keng barglisi	74.8	14.1	14.2 (winter)	38.4 (winter)	91.5 (overwintering)
Spring: Uzbekiskiy	78.4	11.8	11.5 (summer)	34.6 (summer)	92.8 (heat)

Spring: O‘zbekiston keng barglisi	72.5	15.2	10.2 (summer)	29.8 (summer)	86.4 (heat)

3.3. Biochemical characteristics of grain composition: protein, fat, fiber, and beta-glucan

The nutritive and dietary value of oat grain is determined by crude protein, lipids (fat), and water-soluble beta-glucan. Analysis of the biochemical composition of grain from oat cultivars grown on saline soils of Khorezm Region revealed marked genotypic differences.

Grain of spring-sown ‘Uzbekiskiy’ accumulated the highest protein (14.8%) and crude fat (4.9%). Beta-glucan, a valuable bioactive component, reached 4.6% in this cultivar and fully met international dietary standards. In autumn-sown ‘Toshkent 1’, grain protein was 13.4%, crude fat 4.2%, and beta-glucan 4.1%.

In the universal cultivar ‘O‘zbekiston keng barglisi’, grain biochemistry varied with sowing date: under autumn sowing, grain protein was 13.8% and beta-glucan 4.3%; under spring sowing, protein was 14.1% and beta-glucan 4.2%. Crude fiber ranged from 9.8% to 11.2% across cultivars, indicating relatively thin grain hulls and a high proportion of valuable endosperm.

Table 3. Biochemical composition of oat cultivar grain (% of dry matter)

Sowing season and cultivar	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Beta-glucan (%)	Soluble sugars (%)	Ash (%)
Autumn: Toshkent 1	13.4	4.2	10.8	4.1	2.4	3.1
Autumn: O‘zbekiston keng barglisi	13.8	4.5	10.2	4.3	2.6	3.0
Spring: Uzbekiskiy	14.8	4.9	9.8	4.6	2.8	3.2
Spring: O‘zbekiston keng barglisi	14.1	4.4	11.2	4.2	2.5	3.1

3.4. Nutritive value of green forage and stem biomass and yield performance

For livestock farming, the feed value of oat green mass at the stem elongation–heading stages depends on the balance of proteins, sugars, and fiber. Autumn-sown oats provide the earliest juicy, nutritious forage for livestock in early spring (beginning of April).

Under autumn sowing, the universal cultivar ‘O‘zbekiston keng barglisi’ showed the highest green-mass yield—265.0 centners per hectare of quality green forage. Its green mass contained 12.6% crude protein and 8.9% soluble sugars. Autumn-sown ‘Toshkent 1’ yielded 248.0 c/ha of green

forage (11.8% crude protein). Under spring sowing, ‘Uzbekiskiy’ proved outstanding for grain production, yielding 242.5 c/ha of green forage and 33.8 c/ha of grain.

Table 4. Biomass nutritive value and yield indices of oat cultivars

Sowing season and cultivar	Protein in green mass (%)	Sugars in green mass (%)	Green forage yield (c/ha)	Grain yield (c/ha)	1000-grain weight (g)
Autumn: Toshkent 1	11.8	8.2	248.0	28.5	34.2
Autumn: O‘zbekiston keng barglisi	12.6	8.9	265.0	30.8	35.6
Spring: Uzbekiskiy	12.2	8.4	242.5	33.8	37.1
Spring: O‘zbekiston keng barglisi	11.9	8.0	224.0	29.4	34.8

4. XULOSA VA TAVSIYALAR (CONCLUSIONS & RECOMMENDATIONS)

A study of the physiological and biochemical characteristics of oat cultivars under seasonal sowing regimes in the soil–climatic conditions of Khorezm Region led to the following conclusions:

1. Physiological adaptation mechanisms. Under autumn sowing, ‘Toshkent 1’ and ‘O‘zbekiston keng barglisi’ formed cryoprotective and osmoprotective defenses by accumulating sugars (14.2–15.8%) and free proline (38.4–41.2 µmol/g) in the cell sap, ensuring overwintering rates of 91.5–94.2%. Under spring sowing, ‘Uzbekiskiy’ proved most tolerant of drought and salinity owing to high synthesis of chlorophyll a+b (2.84 mg/g) and carotenoids (0.64 mg/g) and high tissue water-retention capacity (78.4%).

2. Biochemical value of grain. Spring-sown ‘Uzbekiskiy’ was identified as the most suitable genotype for human food and dietary processing industries because of high grain protein (14.8%), crude fat (4.9%), and soluble beta-glucan (4.6%).

3. Universal (facultative) plasticity. ‘O‘zbekiston keng barglisi’ was confirmed as a universal cultivar capable of stable development in both autumn and spring seasons. When sown in autumn it formed 265.0 c/ha of highest-quality green forage and 30.8 c/ha of grain; when sown in spring it still yielded 224.0 c/ha of green mass.

Recommendations for production:

• On irrigated saline lands of Khorezm Region, early spring sowing (10–15 March) of ‘Uzbekiskiy’ is recommended for grain and high-protein feed production;

• For an early-spring green forage conveyor and accumulation of high-quality hay and haylage, autumn sowing (10–20 October) of ‘Toshkent 1’ and the universal cultivar ‘O‘zbekiston keng barglisi’ is recommended;

• ‘O‘zbekiston keng barglisi’ is recommended as a reliable dual-season universal cultivar when irrigation water is scarce or when crop-rotation fields become free late.

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