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Selection of promising varieties of Triticosecale for planting in arid regions based on photosynthetic activity, productivity and yield indicators

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ABSTRACT

In recent years, the sharp increase in droughts has led to water shortages, making it even more difficult to conduct farming on non-irrigated lands. The widespread impact of this stress factor also leads to the degradation of natural pastures. In such conditions, research on the selection of promising varieties of drought-resistant crops is of urgent importance. In selecting promising crops and varieties for arid regions, it is important to determine the physiological properties of plants under different water regimes, especially photosynthetic activity and productivity. In this study, experiments were conducted to study the effects of growing under conditions of stable water supply (SWS) and water limitation (WL) on the photosynthetic activity and productivity of Triticosecale varieties. As a result of the experiments, it was found that the values of photosynthetic productivity and grain yield in some varieties among the studied varieties do not differ much from the values observed in plants grown under conditions of moderate water supply. The experiments provided an opportunity to select varieties that are adapted to climate change, are resource-efficient and can produce stable yields. The results obtained can serve to develop eco-agrotechnologies aimed at sustainable cultivation of Triticosecale under conditions of limited water supply, and to maintain and restore the stability of arid regions undergoing degradation through the use of these agrotechnologies.

Keywords: Triticosecale, drought, physiological parameters, degradation, recovery, stabilization.

INTRODUCTION

The global climate shift towards drought poses a serious threat to agricultural production and, in turn, food security. Global warming, reduced precipitation, and soil moisture deficiency are reducing agricultural productivity and making it more difficult to meet the food needs of humanity at a time when the population is rapidly increasing (Ruziyev et al., 2023). For this reason, the world community is paying special attention to the cultivation of crop species that can produce stable yields in arid climates and require less water (Mahmudov et al., 2025). The growth and development of cereal crops in drought conditions are affected by many negative factors, including various rust diseases, insect pests, and agrotechnical difficulties (Akramov et al., 2025; Makhramova et al., 2025). In such conditions, the lack of disease and pest-resistant varieties sharply increases the cost of grain products. This, in turn, requires the development and widespread introduction into practice of new types of cereal crops that are resistant to stress factors, productive and adaptable to agroecological conditions (Urokov et al., 2024; Ergasheva et al., 2024).

Triticosecale is a promising crop derived from a hybrid of wheat and rye, resistant to high temperatures, salinity, low nutrient and water requirements, and highly resistant to diseases. It quickly adapts to adverse soil and climatic conditions, gives stable yields, and has high nutritional value. Therefore, in-depth study of the physiological properties of Triticosecale, in particular, its photosynthetic activity and factors affecting productivity in drought conditions, is currently one of the most urgent issues (Usmanova et al. 2024).

Triticosecale is now an important crop in many countries around the world (Kendal et al., 2016). Originally grown primarily as a grain and green fodder, in recent years Triticosecale grain has been increasingly used for the production of food products, including alcoholic beverages. Since the end of the last century, Triticosecale has been considered a potential energy source. To date, a number of studies have been conducted on the production of biofuels, in particular bioethanol and biogas, from its biomass (Mergoum et al., 2009). Triticosecale is widely used, in particular, for fodder, flour products and green mass (Giunta et al., 1993). Scientific sources indicate that Triticosecale grain is recommended to be added to the feed composition of livestock and poultry in an amount of up to 50% instead of conventional feeds (Tratwal et al., 2021). Its green mass is high in carotenoids and sugars, which distinguishes it as a high-value feed for animals. In countries such as Spain, Hungary, Poland, Canada and the USA, Triticosecale is even grown as a pasture plant (Zhu et al., 2018).

The aim of this study was to determine the mechanisms of drought adaptation of different Triticosecale varieties and to study the effects of growing under moderate and limited water supply conditions on the photosynthetic activity and yield indicators of Triticosecale varieties in order to select stable and productive varieties.

MATERIALS AND METHODS

Research objects and experimental site

The Triticosceles varieties “Farhod”, “Odissey”, “Valentin”, “Svat”, “Tikhon” were used as the research objects. Field experiments were conducted in the irrigated meadow-gray soil areas of the Payariq district of the Samarkand region (39°51’03.2”N 66°54’23.0”E) under model conditions of stable water supply (SWS) and water limitation (WL). In this case, the stable water supply conditions were created by using irrigation that allowed maintaining soil moisture at 70%, and the water limitation conditions were created by using soil moisture at 50%. Other agrotechnical measures were carried out in the same way for all variants. Laboratory experiments were conducted in the scientific laboratory of the Department of Plant Physiology and Microbiology, Institute of Biochemistry, Samarkand State University. All parameters were evaluated by comparing the performance of plants grown under stable water supply (SWS) and water-limited (WL) conditions.

Determination of the amount of pigments in leaves

The amount of pigments in leaves was determined by calculating the amount of chlorophylls and carotenoids in Wettstein’s 96% alcohol solution using SF-26 in the Zlatev method (2023) (Zlatev et al., 2023).

Calculation of photosynthetic net and biomass dry productivity

The photosynthesis productivity (PP) and net photosynthesis productivity (PPn) were calculated by the method of A.A. Nichiporovich using the formula (Nichiporovich 1972):

$$PP = \tfrac{1}{2}\, h \times 1\ m^2/day \quad (1)$$

$$PPn = YBiol./PP(g \times day/m^2) \quad (2)$$

where: h – the leaf surface area on the day of measurement; (m^2) l – duration of the growing period (days); *Ybiol* – biological yield.

The dry matter content was determined by drying to constant mass in a drying cabinet.

Biometric indicators determining productivity and determining yield

The weight of 1000 grains was determined by measuring the weight of 50 grains of each variety and dividing the determined weight by 1000 (Ruziev et al., 2024). Spike length, number of grains per spike, grain weight per spike were studied according to the generally accepted procedure in the method of Guo et al. (2018) (Guo et al., 2018). Yield was determined in centners by determining the total grain mass in 5 plots of 4 m^2 for each variety under conditions of SWS and WL and by proportionalizing kg per 1 m^2 of area to 10.000 m^2 and dividing it by 100 (Ergasheva et al., 2024).

Statistical methods

The digital data obtained in the study were statistically processed using the Statistics Kingdom (https://www.statskingdom.com) and Medical Statistics (https://medstatistic.ru) programs, and the experimental results were statistically summarized by evaluating the arithmetic means of 3–5 replicate experiments at a statistical significance level of $p \leq 0.05$ (Rayimova et al., 2024).

RESULTS

Effect of water regime on the amount of pigments of leaves of Triticosecale

The quantitative changes in plastid pigments, in particular chlorophyll "a", chlorophyll "b" and carotenoids in leaves of Triticosecale varieties were analyzed at different phenological stages of development, under agroecological conditions with stable water supply and water limitation (Table 1).

According to the results of the study, the amount of plastid pigments in Triticosecale varieties differed significantly depending on the plant development phases. The total amount of chlorophyll pigments, as a rule, increased from the budding stage to the flowering stage, and a decrease was observed at the grain ripening stage. In both conditions, the amount of chlorophyll

Table 1. Content of plastid pigments in leaves (n = 3)

Cultivar	Developmental phase	SWS*			WL*		
		Chlorophyll		Carotenoid	Chlorophyll		Carotenoid
		α	β		α	β	
Farhod	Tillering phase	2.67±0.11	1.22±0.11	1.47±0.16	2.63±0.11	1.24±0.11	1.49±0.14
Odyssey		2.91±0.14	1.25±0.10	1.49±0.14	2.85±0.08	1.27±0.11	1.52±0.12
Valentin		2.82±0.11	1.27±0.12	1.52±0.17	2.77±0.14**	1.22±0.09	1.55±0.11
Svat		2.72±0.13	1.24±0.09	1.46±0.14	2.70±0.14	1.23±0.09	1.51±0.14
Tikhon		2.84±0.13	1.28±0.10	1.54±0.14	2.81±0.14	1.25±0.11	1.57±0.13
Farhod	Stem elongation phase	2.93±0.07	1.33±0.12	1.55±0.17	2.85±0.10	1.29±0.11	1.61±0.15
Odyssey		3.12±0.19	1.36±0.13	1.56±0.17	2.98±0.13	1.38±0.14	1.64±0.09
Valentin		3.08±0.15	1.35±0.12	1.58±0.14	2.88±0.17	1.34±0.12	1.68±0.08
Svat		2.92±0.14	1.30±0.10	1.57±0.17	2.92±0.13	1.30±0.10**	1.57±0.13
Tikhon		3.04±0.20	1.34±0.09	1.61±0.10	2.95±0.15	1.35±0.12	1.61±0.12
Farhod	Heading phase	3.19±0.11	1.42±0.11	1.62±0.18	3.09±0.06	1.42±0.10	1.75±0.18
Odyssey		3.35±0.18	1.47±0.15	1.65±0.16	3.27±0.18	1.45±0.14	1.87±0.08
Valentin		3.32±0.16	1.46±0.11	1.66±0.07	3.12±0.23	1.46±0.10	1.81±0.17
Svat		3.25±0.15	1.44±0.13	1.64±0.11	3.22±0.16	1.42±0.12	1.87±0.11
Tikhon		3.29±0.18	1.47±0.16	1.64±0.11	3.25±0.18**	1.47±0.13	1.84±0.11
Farhod	Flowering phase	3.21±0.11	1.46±0.14	1.73±0.15	3.15±0.09	1.49±0.14	1.96±0.11
Odyssey		3.39±0.17	1.53±0.16	1.77±0.16	3.32±0.16	1.48±0.13	1.98±0.13
Valentin		3.35±0.18	1.51±0.14	1.76±0.12	3.11±0.23	1.44±0.14	1.87±0.13**
Svat		3.27±0.17	1.49±0.14	1.73±0.07	3.25±0.20	1.45±0.13	1.97±0.12
Tikhon		3.33±0.16	1.51±0.08	1.75±0.14	3.29±0.15	1.50±0.10	1.95±0.13
Farhod	Grain filling phase	2.81±0.18	1.32±0.12	1.85±0.17	2.76±0.15	1.39±0.13	2.08±0.15
Odyssey		2.99±0.15	1.41±0.12	1.89±0.15	2.93±0.14	1.35±0.11	2.12±0.14
Valentin		2.95±0.14	1.39±0.11	1.84±0.06	2.72±0.13	1.32±0.10**	2.01±0.19
Svat		2.89±0.15	1.36±0.10	1.82±0.07	2.86±0.13	1.36±0.10	2.11±0.16
Tikhon		2.92±0.15	1.39±0.06	1.84±0.09	2.89±0.15	1.39±0.09	2.10±0.16

Note: *SWS – stable water supply; WL – water limited; **statistically significant at $p < 0.05$.

"a" was higher than that of chlorophyll "b". The amount of carotenoids was also characterized by a gradual increase during the vegetation period. Under conditions with stable water supply, the highest amount of pigments was determined in the flowering phase. In particular, the amount of chlorophyll "a" was in the range of 3.21–3.39 mg/g, chlorophyll "b" was in the range of 1.46–1.53 mg/g. Carotenoids were recorded to reach 1.73–1.77 mg/g at this stage.

Under water-limited conditions, the content of chlorophyll "a" in the flowering phase ranged from 3.11–3.32 mg/g, and chlorophyll "b" from 1.44–1.50 mg/g. Notably, the content of carotenoids was relatively higher under water-limited conditions, increasing to 1.87–1.98 mg/g. In general, although the total content of chlorophyll pigments was slightly higher in all varieties studied under conditions of stable water supply, the content of carotenoids prevailed in varieties under water-limited conditions. Under both conditions, the variety Odysseus was distinguished by a high concentration of plastid pigments, which indicates the relative resistance of this variety to stress.

The effect of water regime on net photosynthetic productivity of Triticosecale

Net photosynthesis productivity is an important physiological process that determines the photosynthetic activity of crops. The level of net photosynthesis productivity is of great importance in the cultivation of cultivated plants. The amount of organic matter formed as a result of photosynthesis depends on a number of factors, and varies depending on external abiotic factors, the biological characteristics of varieties, and the results of agrotechnical measures taken. In our research, we studied the net photosynthesis productivity in the development phases of Triticosecale varieties under two different conditions (with a stable supply of water and with limited water) (Figure 1).

In all Triticosecale varieties, net photosynthesis productivity increased from the head phase to the flowering phase under both conditions, while a decrease in net photosynthesis productivity was observed in the grain ripening phase. In Triticosecale varieties, net photosynthesis productivity had the highest index in the flowering phase. In conditions of stable water supply, it was found that in the flowering phase, the Odyssey variety was 9.51 g/m^2 day, while in the Farkhod variety it was 8.30 g/m^2 day. The remaining varieties occupied an intermediate position. In the flowering phase, the relatively low net photosynthesis productivity in water-limited conditions was found to be 7.55 g/m^2 day in the Valentin variety, while the highest index among the varieties was found to be 8.01 g/m2 day in the Odyssey variety.

It was observed that the net photosynthetic productivity of Triticosecale varieties grown under conditions of stable water supply was slightly higher in all phases than in water-limited conditions. It was found that the

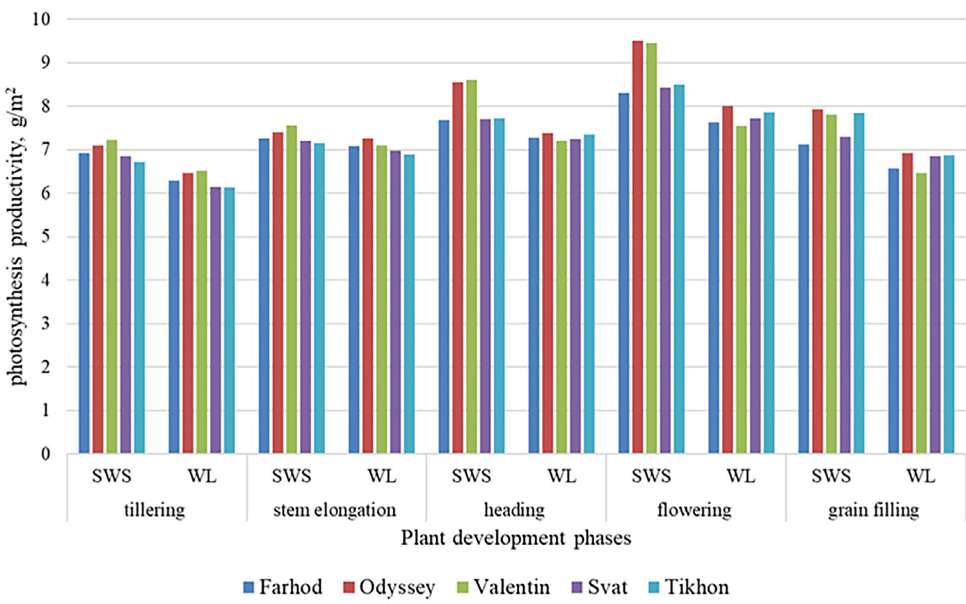

Figure 1. Photosynthetic productivity at different stages of Triticosecale cultivars grown under stable water supply (SWS) and water-limited (WL) conditions (n = 3)

net photosynthetic productivity was higher in the varieties Odyssey and Valentin in all phases under stable water supply conditions, and in the varieties Odyssey and heading in all phases under water-limited conditions and in the later phases in the varieties Tikhon.

The effect of water regime on biomass productivity of Triticosecale

The biomass production of plants is closely related to their genetic characteristics, environmental conditions and developmental stages. In this study, the dry matter (biomass) production of Triticosecale varieties under water-limited and water-stable conditions was evaluated during the growth phases (Figure 2).

According to the analysis results, dry matter production in all varieties increased with increasing growth phases. Under water-stable conditions, the highest dry matter production was observed during the flowering and grain ripening phases. In particular, during the flowering phase, the Valentin variety produced 36.4 g/bush, the Odyssey 34.9 g/bush, and the Farhod 32.9 g/bush biomass. During the grain ripening phase, the highest results were obtained for the Valentin (39.8 g/bush) and Odyssey (38.5 g/bush) varieties. Under water-limited conditions, dry matter production was relatively low, which is thought to be due to limited soil water availability. However, some varieties, in particular Odyssey and Valentin, were more drought-tolerant. At the grain ripening stage, Odyssey (33.6 g/bush) and Valentin (32.3 g/bush) varieties maintained high biomass. In Swat and Tikhon varieties, biomass production was relatively low under both conditions, indicating that these varieties have a lower dry matter production potential. In general, among Triticosecale varieties, Valentin and Odysseus have high biomass production rates and can be recommended as varieties resistant to drought conditions.

The effect of water regime on biometric indicators of productivity of Triticosecale

The study analyzed the yield-related traits of Triticosecale varieties under both water-limited and water-stable conditions (Table 2).

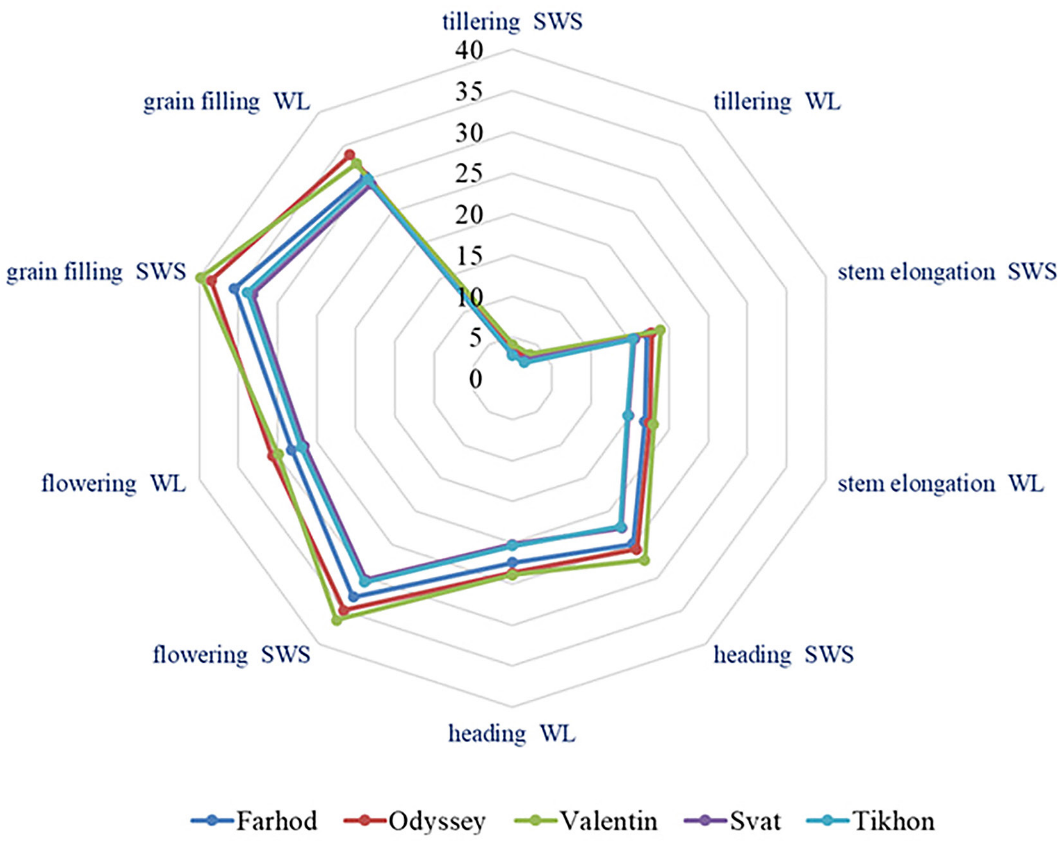

Figure 2. Dry biomass productivity, g/plant, at different phases of Triticosecale varieties grown under stable water supply (SWS) and water-limited (WL) conditions (n = 3)

Table 2. Yield-related traits of Triticosecale cultivars under moderate and drought conditions (n = 5)

Cultivar	Spike length (cm)		Number of grains per spike		Grain weight per spike (g)		1000 grain weight	
	*SWS	*WL	SWS	WL	SWS	WL	SWS	WL
Farhod	13.8±0.38	13.2±0.52	54.7±2.9	51.5±2.4	2.4±0.04	2.2±0.11	45.6±1.01	43.5±1.21
Odyssey	14.5±0.60	14.0±0.56	60.3±2.1	57.5±2.4**	2.7±0.14	2.5±0.10	47.5±1.16	45.3±1.14
Valentin	13.8±0.48	13.0±0.58**	57.4±2.5	52.6±3.0	2.5±0.11	2.2±0.11	43.7±1.19	42.1±1.27**
Svat	13.4±0.50	13.0±0.63	51.5±2.4	49.3±2.5	2.4±0.07	2.3±0.11	46.7±1.12	43.9±1.13
Tikhon	12.6±0.52	12.3±0.58	50.7±2.4	48.7±2.6	2.5±0.10	2.4±0.08**	50.8±1.21	48.2±1.31

Note: *SWS – stable water supply; WL – water limited; **statistically significant at $p < 0.05$.

The results showed that drought stress negatively affected all measured parameters, i.e., spike length, number of grains per spike, grain weight per spike, and 1000-grain weight. However, this reduction was different for each variety, indicating that the level of drought tolerance among Triticosecale varieties is related to genotypic differences. Under water-stable conditions, the Odysseus variety showed the highest results: spike length – 14.5 cm, number of grains per spike – 60.3 grains, and grain weight per spike – 2.7 g. Although these indicators decreased slightly under water-limited conditions, the Odysseus variety still maintained relatively high results, indicating that it was well adapted to water scarcity.

The Farhod variety was selected as a control variety and showed a moderate decrease under water-limited conditions: spike length decreased from 13.8 cm to 13.2 cm, the number of grains per spike decreased from 54.7 to 51.5, and the 1000-grain mass decreased from 45.6 g to 43.5 g. This decrease was relatively lower than that of the Valentin and Swat varieties, which had significantly reduced grain number and spike mass. It is noteworthy that the Tikhon variety showed the highest 1000-grain mass under both water-limited (50.8 g) and water-limited (48.2 g) conditions. This means that despite the decrease in spike length and grain number, its grains remained almost unchanged in terms of volume.

These results confirm the differences in drought response among Triticosecale varieties. In particular, the varieties Odyssey and Tikhon are recommended as promising varieties for cultivation in water-stressed regions, due to their more stable yield characteristics.

The effect of water regime on the yield of Triticoscele

During the research, the productivity of Triticosecale varieties was evaluated by comparing agrocenoses under water-limited and water-stable agroclimatic conditions. Under water-stable conditions, the productivity ranged from 80.8 centners/hectare for the Farkhod variety to 107.07 centners/hectare for the Odyssey variety, while under drought conditions, this indicator varied from 67.17 centners/hectare for the Valentin variety to 87.40 centners/hectare for the Odyssey variety (Table 3).

Among the Triticosecale varieties, the Odyssey and Tikhon varieties were distinguished by a high level of drought tolerance, water retention capacity, stable pigment system, and organic matter accumulation. These physiological traits indicate drought tolerance. On the contrary, the Valentin variety showed the strongest sensitivity to water deficit, which indicates its low level of physiological tolerance.

Table 3. Grain yield of Triticosecale varieties, c/ha (n = 5)

Cultivar	2022		2023		2024	
	*SWS	*WL	SWS	WL	SWS	WL
Farhod	77.4±3.4	67.3±2.6	84.8±3.7	73.5±2.8	80.2±3.8	72.1±2.2
Odyssey	106.2±2.4	84.5±2.0**	108.6±2.3	87.5±2.1	106.3±2.1	90.1±2.1
Valentin	85.3±1.4	65.5±1.5	91.2±1.2	70.9±1.2	92.5±2.2	65.1±2.6**
Svat	83.7±1.2	72.6±2.7	86.5±1.7	76.4±2.6	84.6±2.8	75.1±2.8
Tikhon	81.3±2.4	78.4±0.9	86.1±0.6	82.2±0.9**	94.6±0.5	81.5±2.8

Note: *SWS - stable water supply; WL - water limited; **statistically significant at $p < 0.05$.

DISCUSSION

As one of the promising crops in agriculture, the mechanisms of physiological processes and adaptive properties of Triticosecale varieties under the influence of various environmental stress factors have been studied by a number of foreign and domestic researchers (Mukhtorova et al., 2024). The high productivity of Triticosecale varieties is directly related, in particular, to their stomatal activity, in which a high rate of carbon assimilation and low respiratory intensity are recognized as important factors. The crop's resistance to abiotic stresses - in particular, drought, salinity, low pH, nutrient deficiency or excess, and waterlogging - is associated with the presence of a rye component in its genome. Triticosecale is also close to rye in terms of cold resistance (Zhukov et al., 2022). In addition, Triticosecale is a crop with high genetic diversity. Therefore, some of its varieties show strong resistance to various adverse factors. However, it would be wrong to consider each variety as tolerant to abiotic stress, since resistance depends on the genetic characteristics of each species (Blum, 2014). Under drought stress, plants exhibit various physiological and biochemical adaptation mechanisms. One of them is the accumulation of soluble carbohydrates (including sucrose, glucose, and fructose) inside the cells to maintain osmotic balance. The concentration of these substances serves as an important indicator of the degree to which the plant is exposed to stress (Huang et al., 2011).

Unlike wheat and barley, Triticosecale crops have a high tolerance to water deficit. This is particularly evident in photosynthetic activity, with water deficit having a less negative impact on photosynthesis in Triticosecale than in other cereals (Roohi et al., 2013). According to Méndez-Espinoza, soil moisture deficits in the Mediterranean region are mainly observed in the spring and summer months, leading to a sharp decrease in grain yield. Studies show that even under water-stressed conditions, Triticosecale grain yields are often higher than those of wheat. However, its water-resistance mechanisms and physiological properties have not yet been fully studied (Méndez-Espinoza et al., 2019).

According to international forecasts, by 2050, the global demand for cereals will increase by 42–59%, while prices may increase by 13–30% (Fischer et al., 2014). This situation necessitates the development and implementation of high-yielding, environmentally stress-resistant crop varieties (Khojakulov et al., 2024). Triticosecale is one of the promising crops that can be used in many areas in this regard. It is known that more than 90% of plant biomass is formed due to the products of photosynthesis. Therefore, nitrogen and water supply are among the main factors controlling productivity (Olszewski et al., 2014).

Nitrogen nutrition is a crucial factor that directly affects the intensity of photosynthesis, the synthesis of carbon compounds and the accumulation of total biomass in plants. Enhancing the photosynthesis process and adapting it to environmental conditions is one of the important agrotechnical goals in agriculture (Gonzalez et al., 2010). Photosynthetic activity is significantly affected by a number of external and internal factors, in particular, leaf age, architecture and location (Olszewski et al., 2014), as well as factors such as air temperature, light intensity, nutritional status and water regime (Garofalo et al., 2015; Ergashev et al., 2025). In addition, changing humidity and temperature conditions as a result of global climate change can also disrupt the photosynthesis process (Hura et al., 2011). Photosynthetic properties also differ significantly between plant genotypes and their growth stages (Gonzalez et al., 2010). Photosynthetic intensity can even vary with nutritional status (Olszewski et al., 2014), which is important for developing breeding and agronomic management strategies.

These analyses confirm that photosynthetic activity and productivity in Triticosecale under water-limited conditions are based on physiological mechanisms.

CONCLUSIONS

This study was conducted for the first time in Uzbekistan to determine the effect of water-limited field conditions on the main physiological indicators of plant productivity of Triticosecale varieties and their effect on the yield of plants. As a result of the studies, it was noted that water limitation leads to a decrease in the amount of pigments in the leaves, photosynthesis and dry matter productivity, as well as grain yield in Triticosecale varieties. However, the Odyssey and Tikhon varieties showed drought tolerance, and the studied indicators were close to those of plants under conditions of stable water supply. In areas subject to degradation in arid and semi-arid regions, it is recommended to implement measures that ensure natural stability by planting and cultivating the Odyssey and Tikhon varieties.

REFERENCES

1. Akramov, I., Alikulov, B. S., Axanbayev, S., Norboyev, M., Safarova, D., Ismailov, Z., Kuziev, M., Ruziev, Yu., Tursunov, A. (2025). Application of endophytic bacteria synthesizing indolyl acetic acid isolated from *Krascheninnikovia ceratoides* (L.) Gueldenst in wheat cultivation under saline conditions. *Journal of Ecological Engineering*, *26*(8), 97–107. https://doi.org/10.12911/22998993/203742
2. Blum, A. (2014). The abiotic stress response and adaptation of triticale – A review. *Cereal Research Communications, 42*, 359–375. https://doi.org/10.1556/CRC.42.2014.3.1
3. Ergashev, A., Alikulov, B. S., Valiyev, S., Sodikova, D., Boboxonov, M., Nurmatov, R...., Rakhmatullaev, B. (2025). Adaptive physiological traits of *Artemisia absinthium* L. seedlings grown in vitro for establishment in arid environments. *Journal of Ecological Engineering*, *26*(11).
4. Ergasheva, X.I., Ismoilov, Z.F., Alikulov, B.S., Jo'raqulovna, N.X., Tillaeva, Z.F., Abdullaev, I.I., Raxmatullayev, A.Y., Ergasheva, O.K. (2024). Biotechnological processing of organic and domestic waste and the effect of obtained vermicompost on soil fertility. *Journal of Ecological Engineering 25*(8), 119–129. https://doi.org/10.12911/22998993/189894
5. Ergashova, D.U., Sanakulov, A.L., Jumakulova, N.S., Khujanov A.N. (2025). Effects of Zn, Cu, Mn, and Co on nitrogen metabolism of *Cucumis melo* L. varieties. *American Journal of Plant Sciences 16*(2158–2742), 485–493. https://doi.org/10.4236/ajps.2025.164036
6. Fischer R.A., Byerlee D. and Edmeades G.O. (2014). Crop yields and global food security: will
7. Garofalo, P., Rinaldi, M. (2015). Leaf gas exchange and radiation use efficiency of sunflower (*Helianthus annuus* L.) in response to different deficit irrigation strategies: from solar radiation to plant growth analysis. *Eur J Agr 64*, 88–97. https://doi.org/10.1016/j.eja.2014.12.010
8. Giunta, F., Motzo, R., Deidda, M. (1993). Effect of drought on yield and yield components of durum wheat and Triticosecale in a Mediterranean environment. *Field Crops Research 33*(4), 399–409. https://doi.org/10.1016/0378-4290(93)90161-F
9. Gonzalez, A., Bermejo, V., Gimeno, B.S. (2010). Effect of different physiological traits on grain yield in barley grown under irrigated and terminal water deficit conditions. *J Agric Sci 148*, 319–328.
10. Guo, Z., Zhao, Y., Röder, M.S., Jochen, C.R., Martin, W.G., Dijun, C., Thorsten, S. (2018). Manipulation and prediction of spike morphology traits for the improvement of grain yield in wheat. *Sci Rep 8*, 14435. https://doi.org/10.1038/s41598-018-31977-3
11. Huang, H.X., Wang, G., Chen, N.L. (2011). Advanced studies on adaptation of desert shrubs to environmental stress. *Sciences in Cold and Arid Regions 3*, 455–462.
12. Hura, T., Hura, K., Grzesiak, M. (2011). Soil drought applied during the vegetative growth of Triticosecale modified the physiological and biochemical adaptation to drought during the generative development. *J Agron Crop Sci 197*, 113–123. https://doi.org/10.1111/j.1439-037X.2010.00450.x
13. Kendal, E., Sayar, M. S., Tekdal, S., Aktas, H., Karaman, M. (2016). Assessment of the impact of ecological factors on yield and quality parameters in Triticosecale using GGE biplot and AMMI analysis. *Pakistan Journal of Botany 48*(5), 1903–1913.
14. Khojakulov. D., Khaydarov, Kh., Rabbimov, A., Mukimov, T., Matkarimova, G., Davronkulova, F., Ochilov, U., Alikulov, B.S. (2024). Biological, physiological and economic characteristics of *Onobrychis chorasanica* Bunge ex Bois. (Sainfoin) under sowing conditions. *Plant Science Today, 11*(3), 14–21. https://doi.org/10.14719/pst.3180
15. Makhramova, M., Urokov, S., Akzamov, V., Rajamuradova, N., Kuzieva, S. (2025). Development and application of *Secale cereale* L cultivation technology based on optimal physiological parameters for arid conditions. *Journal of Ecological Engineering*, *26*(11).
16. Méndez-Espinoza, A.M., Romero-Bravo, S., Estrada, F., Garriga, M., Lobos, G.A, Castillo, D., Matus, I., Aranjuelo, I., del Pozo, A. (2019). Exploring agronomic and physiological traits associated with the differences in productivity between triticosecale and bread wheat in mediterranean environments. *Front. Plant Sci. 10*, 404. https://doi.org/10.3389/fpls.2019.00404
17. Mergoum, M., Singh, P.K., Peña, R.J., Lozano-del Río, A.J., Cooper, K.V., Salmon, D.F., Gómez, Macpherson H. (2009). *Triticosecale: A "New" Crop with Old Challenges.* Cereals. New York: Springer, 356.
18. Mukhtorova, S., Alikulov, B., Yuldosheva, M., Maxammadieva, D., Khidirova., U., Kabulova, F., Ismailov, Z. (2024). Diversity of endophytic bacteria isolated from Peganum harmala distributed in arid regions in Uzbekistan. *Regulatory Mechanisms in Biosystems*, *15*(2), 286–291. https://doi.org/10.15421/022441
19. Muminov, M., Nosirov, M., Mukimov, T., Normuradov, D., Khodjibabayev, Kh., Ismailkhujaev, B., Urokov, S., Kholiyev, A., Eshquvvatov, B., Mamadoliev, I. (2025). Multi-faceted analysis of

land use impact on rangeland health: Insights from normalized difference vegetation index assessment in stream, road, and mining areas. *Journal of Ecological Engineering 26*(1), 196–203. https://doi.org/10.12911/22998993/195472

20. Nichiporovich, A.A. (1972). Photosynthetic activity of plants and ways to increase their productivity. In Theoretical foundations of photosynthetic productivity 511–527, Nauka [in Russian].
21. Olszewski, J., Makowska, M., Pszczółkowska, A., Okorski, A., Bieniaszewski, T. (2014). The effect of nitrogen fertilization on flag leaf and ear photosynthesis and grain yield of spring wheat. *Plant Soil Environ 60*, 531–536. https://doi.org/10.17221/880/2013-PSE
22. Rayimova, F., Dushanova, G., Alikulov, B., Kamalov, Z., Ruzibakieva, M., Nabiyeva, F., Rajabov, A. (2024). The role of VDR and TNF gene polymorphism in cytokine regulation in type I diabetes mellitus of the Uzbek population, Samarkand, Uzbekistan. *Biodiversitas*, *25*, 1329–1336. https://doi.org/10.13057/biodiv/d250349
23. Roohi, E., Tahmasebi, S.Z., Modares Sanavi, S.A.M. Sioseh, M.A. (2013). Comparative study on the effect of soil water stress on photosynthetic function of Triticosecale, bread wheat, and barley. *Journal Of Agricultural Science And Technology (Jast) 2*, 215–228. http://dorl.net/dor/20.1001.1.16807073.2013.15.2.17.6
24. Ruziyev, F., Djabbarov, I., Olimjonova, S., Niyozov, U., Urokov, S., Ishankulova, D., Bakhadirov, U. (2023). Grain quality indicators and their phenotypic variability of ancient cultivars of *Triticum aestivum* in the mountains of Uzbekistan. *Biodiversitas 24*, 5995–6001. https://doi.org/10.13057/biodiv/d241119
25. Tratwal, A., Bocianowski, J. (2021). Suitability of winter Triticosecale varieties for composing crop mixtures. *Current Plant Biology 25*, 100182. https://doi.org/10.1016/j.cpb.2020.100182
26. Urokov, S., Usmanova, M., Xadjayev, Dj., Jurayeva, Z., Khujanov, A., Raimkulova, M. (2024). Effects of salinity and drought of germination parameters of seeds of Triticosecale. *Journal of Ecological Engineering 25*(7), 178–186. https://doi.org/10.12911/22998993/188333
27. Usmanova, M., Urokov, S., Xadjayev, Dj, Jurayeva, Z, Keldiyarova, X., Valiyev Sh. (2024). The influence of conditions on water holding capacity characteristics of Triticosecale varieties planted in the Samarkand region. *Plant Science Today 11*(4), 752–760. https://doi.org/10.14719/pst.3287
28. Will yield increase continue to feed the world? ACIAR Monograph No. 158. Australian Centre for International Agricultural Research: Canberra. 634.
29. Zhu F. (2018). Triticosecale: Nutritional composition and food uses. *Food Chem 15*(241), 468–479. https://doi.org/10.1016/j.foodchem.2017.09.009
30. Zhukov, A.M., Anosova, M.V., Popov, I.A., Churikova, S.Yu., Manzhesov, V.I. (2022). Biochemical properties of Triticosecale. Triticosecale sprouts in food technology. *IOP Conf. Series: Earth and Environmental Science 1052*, 012029.
31. Zlatev, Z., Stoykova, V., Shivacheva, G., Vasilev, M. (2023). Design and implementation of a measuring device to determine the content of pigments in plant leaves. *Applied System Innovation, 6*(4), 64. https://doi.org/10.3390/asi6040064