RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (2) 403-413, 2025
http://doi.org/10.54910/sabrao2025.57.2.1
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

WHEAT RESISTANCE TO YELLOW RUST BASED ON MORPHOPHYSIOLOGICAL AND YIELD CHARACTERISTICS

S. MELIEV[1*], B. CHINIKULOV[1], B. OCHILOV[1], KH. NURMETOV[2], U. BAKHODIROV[3], S. BUZURUKOV [1], F. MATKARIMOV [1], F. SOBIROV[4], KH. TURAKULOV[1], and T. BOZOROV[1]

[1]Institute of Genetics and Plants Experimental Biology, Academy of Sciences, Tashkent, Uzbekistan
[2]Department of Evolution Biology and Genetics, Chirchik State Pedagogical Institute, Chirchik, Uzbekistan
[3]Plant Genetic Resources Scientific Research Institute Tashkent, Uzbekistan
[4] Department of Genetics and Biotechnology, Samarkand State University named after Sh.R. Rashidov, Samarkand, Uzbekistan
*Corresponding author's email: meliev.sodir@mail.ru
Email addresses of co-authors: genetik8181@mail.ru, behruz.ochilov1995@mail.ru, xushnud.nurmetov.85@mail.ru, sanjarbuzuruk@mail.ru, farrux_matkarimov@mail.ru, umiddjan@inbox.ru, faridun.sobirov@internet.ru, sadullaevich@yahoo.com, tohirbozorov@yahoo.com

SUMMARY

An association of biotic and abiotic stress resistance has existed with modifying the genetic makeup of plant cells, and as a result, variations occur in some physiological and biochemical processes. Relatedly, the collection of bread wheat (*Triticum aestivum* L.) germplasm and its assessment through morphological, genetic, and physiological parameters are practically significant. Studying the influence of the genotype-environment on the physiological and quantitative characteristics of bread wheat germplasm in Uzbekistan resulted in the environment influencing the wheat genotypes, with a hydrothermal coefficient of Ij = 1.43 in 2017. It gave the average grain yield from all the wheat nurseries at 6.84 t/ha. Meanwhile, in 2019, the hydrothermal coefficient was Ij = 0.69 with a grain yield of 6.77 t/ha. However, when the hydrothermal coefficient decreased to a negative value (Ij = -2.8), the average yield decreased to 6.48 t/ha. The identification of wheat genotypes succeeded according to environmental plasticity (bi) and stability coefficient (Si2) indicators, i.e., K-64 (bi = 0.5, Si2 = 1.8), K-74 (bi = 0.7, Si2 = 1.9), and genotype K-100 (bi = 0.4, Si2 = 0.9).

Keywords: Bread wheat (*T. aestivum* L.), genetic attributes, morphological traits, physiological processes, leaf, carotenoid, grain yield

Communicating Editor: Dr. Himmah Rustiami

Manuscript received: August 17, 2024; Accepted: November 23, 2024.

Citation: Meliev S, Chinikulov B, Ochilov B, Nurmetov KH, Bakhodirov U, Buzurukov S, Matkarimov F, Sobirov F, Turakulov KH, Bozorov T (2025). Wheat resistance to yellow rust based on morphophysiological and yield characteristics. *SABRAO J. Breed. Genet.* 57(2): 403-413. http://doi.org/10.54910/sabrao2025.57.2.1.

Key findings: Regression analysis showed a one-mg increase in total chlorophyll content raised the productivity of 50 selected bread wheats (*T. aestivum* L.) genotypes by 12%. The three-year average of total chlorophyll ranged from 3.34 to 2.03 mg/g, with productivity also significantly reduced in wheat genotypes with low chlorophyll content.

INTRODUCTION

Agriculture is one of the main sectors of economic development, and the population constantly ensuring food security is one of the main tasks of the country manages because food security depends on economic, environmental, and democratic factors. Climate change is one of the global problems of the 21st century, which has a chief impact on the agriculture sector (Lves and Schmidt, 2022). At present, observations on climate change have shown a greater influence on crop plants worldwide. Climate change, land and water, energy resources, and environmental factors are the main challenges to food security strategies (Chandio *et al*., 2023; Azimov *et al*., 2024).

Wheat (*Triticum aestivum* L.) is the primary cereal and staple crop, ensuring food safety. Currently, cultivated wheat cultivars must be high-yielding with better grain quality and resistant to various diseases and unfavorable environmental conditions like biotic and abiotic stresses (Bakhodirov *et al*., 2021; Meliev *et al*., 2023a, b). In the identification and selection of high-yielding cultivars, the genotype and environment interactions (GEI) require high consideration, as they are vital in managing the cultivars' grain yield under different environmental conditions. Past findings also enunciated that different genotypes respond differently to the same conditions, and the same genotype responds differently to varied environmental conditions (Baboeva *et al*., 2023).

High temperatures cause a significant decrease in wheat yield, especially during grain filling, shortening the formation period of crop components. An evaluation and identification of the wheat gene pool through developing natural and artificial high-temperature stress environments is indispensable. Moreover, the high temperature can be useful in determining the prime characteristics of wheat genotypes and selecting the desirable genotypes (Kumar *et al*., 2022).

Through the years, Uzbekistan has risen 12 spots (from rank 85 to rank 73) out of 113 nations in the Global Food Security Index. It now ranks first among the top 10 countries with the fastest growth. The World Bank has also cautioned that unless a change in water distribution occurs, Uzbekistan, as a nation relying on irrigated agriculture for 95% of its productivity, will greatly suffer from climate change. Additionally, a prediction has surfaced that the nation's annual water deficit will reach seven billion cubic meters by 2030 and 15 billion cubic meters by 2050. The Intergovernmental Panel on Climate Change reports that temperatures in Central Asia quickly increase more than the global average. Eventually, this will worsen the drought.

Glaciers are also melting at an unprecedented rate in the region (https://uza.uz/posts/571956). In solving these problems, the first step is developing climate-resistant wheat cultivars. According to the Ministry of Agriculture, in 2023, the grain harvest amounted to more than 8.1 million tons produced by farms and agricultural enterprises in Uzbekistan. As a result, the average grain yield increased from 7.05 tons in irrigated areas (https://zamon.uz/uz-to/detail). This is definitely one of the reasons for introducing and developing local cultivars suitable for a given climate. The value of each wheat cultivar gains distinction by its plasticity and stability to a specific degree of potential productivity under different environmental conditions (Prysiazhniuk *et al*., 2020).

Under diverse growing conditions, the common wheat plant exhibits phenotypic variability with the influence of various environmental factors. With climate change, the phenotypic variability in wheat genotypes refers to phenotypic plasticity (Grogan, 2016). This term suits to explore the physiological and morphological variabilities of genotypes under the influence of various environmental factors during periods of development. In contrast, the advantage of selection based on physiological and morphological traits has markers of early and normal grain yield easily identifiable from yield-attributing traits (OECD-FAO, 2018). In breeding, the proper phenotyping and its application combined with molecular information based on the genetic principles will improve its efficiency (Fujino *et al*., 2019).

In this case, the process of indirect selection aimed at physiological traits is considerably more effective than selection aimed at productive traits (Sabri *et al*., 2020). Therefore, the presented study aimed to evaluate the differences in morphological and physiological traits for increasing the grain yield of heat-tolerant and temperature-sensitive wheat genotypes. Additionally, the study sought to identify the key characteristics beneficial in the selection and development of climate-resistant wheat genotypes.

MATERIALS AND METHODS

The study commenced in 2017 to 2019 at the Tashkent Region of Uzbekistan (41.2322° N and 69.2754° E). The experiments happened at the Dormon Experimental Site, Institute of Genetics and Plant Experimental Biology, Academy of Sciences of Uzbekistan, Tashkent Region, Uzbekistan. This paper reports the dependence of the wheat resistance index on yellow rust disease based on the physiological, morphological, and yield-related traits and their adaptability under natural climatic conditions.

Plant material

Research materials comprised using elite high-yielding cultivars of the spring wheat gene pool (38th – ESWYT: Elite Spring Wheat Yield Trial) and the samples of high-temperature-resistant wheat (16th HTWYT: High-Temperature Wheat Yield Trial), procured from the International Maize and Wheat Improvement Center (CIMMYT), Mexico. The cultivar Krasnodarskaya-99 served as the control genotype, released in Uzbekistan, as a jointly developed cultivar with the Krasnodar KHITI named after P. Lukyanenko and the North Kuban Agricultural Research Station. All the wheat genotypes' planting was in 2 m^2-wide subplots with three replications.

Data recorded and analysis

The leaf area, photosynthesis, and chlorophyll content analysis on 10 plant leaves proceeded and then averaged. In all the wheat genotypes, recording the data on plant height, plant biomass, 1000-grain weight, and grain productivity ensued.

RESULTS

Environment impact on productivity

Based on the results of the wheat genotypes' grain yield, the established average annual grain yield of the wheat collected germplasm was Yi = 6.69 t/ha, which was 0.39 t/ha higher than the standard cultivar Krasnodar-99 (6.30 t/ha). On grain yield, the standard cultivar showed high results in 17 samples. The overall average grain yields of the collected genotypes for three years were 6.69 t/ha. However, the highest grain yield resulted in the genotypes K-7 (7.07 t/ha), K-13 (7.16 t/ha), K-32 (6.77 t/ha), K-46 (6.89 t/ha), K-64 (7.76 t/ha), and K-89 (6.86 t/ha), and the yield was above average (Table 1).

Analyzing the stress resistance based on productivity revealed the hydrothermal coefficient (HTC) as 1.43 in 2017, and the said values were -2.82 and 0.69 in 2018 and 2019, respectively. During the study, the most favorable conditions were evident in the years 2017 and 2019. In 2017, the value of the environmental index was equal to Ij = 1.43, and the total yield was 6.84 t/ha. In 2018, a relatively negative value (Ij = -2.8) appeared, and the total yield decreased to 6.48 t/ha. For 2019, the conditions were relatively favorable with the value of Ij = 0.69, and the total yield was 6.77 t/ha. These stressful meteorological conditions made it possible to determine the adaptability of the studied samples (Table 1).

Table 1. Adaptability index of wheat germplasm with the environment's influence on the grain yield in wheat.

Catalog number	Grain yield (t/ha)			Yi	Уmin-Уmax	Уmin+Уmax/2	bi	Si^2
	2017	2018	2019					
7	6.80	7.70	6.70	7.07±3.15	-10.0	72.0	2.7	1.3
8	6.83	5.20	7.63	6.56±7.16	-24.3	64.2	5.6	10.5
13	6.31	7.70	7.47	7.16±4.29	-13.9	70.0	2.7	27.7
20	7.03	5.17	7.43	6.54±6.98	-22.7	63.0	5.8	120.0
21	7.15	5.90	6.93	6.66±3.86	-12.5	65.3	3.4	34.7
32	7.15	5.97	7.20	6.77±4.02	-12.3	65.8	4.0	1.4
41	6.33	7.16	5.33	6.28±5.28	-18.3	62.5	4.0	10.1
46	6.37	7.35	6.97	6.89±2.86	-9.8	68.6	2.5	1.2
47	6.70	5.40	6.60	6.23±4.17	-13.0	60.5	4.2	1.5
49	7.20	5.77	6.50	6.49±4.13	-14.3	64.8	3.9	2.2
56	7.13	5.50	7.20	6.61±5.55	-17.0	63.5	5.5	0.9
60	7.27	6.25	6.47	6.66±3.09	-10.2	67.6	2.4	3.8
61	6.15	6.40	5.77	6.11±1.84	-6.3	60.8	1.3	0.3
64	7.64	7.85	7.80	7.76±1.63	-2.1	77.5	0.5	1.8
74	6.70	6.90	6.63	6.74±8.01	-2.0	67.7	0.7	1.9
80	6.83	7.10	6.27	6.73±2.45	-8.3	66.8	1.6	1.7
81	7.18	5.87	6.83	6.63±3.93	-13.2	65.3	3.9	0.9
82	6.55	7.25	6.13	6.64±3.26	-11.2	66.9	2.8	0.4
89	6.83	6.60	7.13	6.86±1.54	-5.3	68.7	1.1	0.9
100	6.66	6.65	6.33	6.55±1.07	-3.3	65.0	0.4	0.9
Krasnodar-99	6.40	5.80	6.70	6.30±1.20	-9.0	62.5	2.4	0.6
Yi	6.84	6.48	6.77	6.69±3.46				
Ij	1.43	-2.82	0.69					

In the second year (2018), the level of the hydrothermal coefficient of atmospheric humidity decreased relatively, causing a decrease in the total yield to 6.48 t/ha. It was apparent that in wheat genotype K-64 (7.85 t/ha), unlike samples with a high level in the first year, the grain yield did not decrease, indicating its supreme genetic potential for its productivity. Stable favorable conditions were notable during 2019, and the wheat samples K-8 (7.63 t/ha), K-13 (7.47 t/ha), K-20 (7.43 t/ha), K-21 (6.93 t/ha), K-32 (7.20 t/ha), K-46 (6.97 t/ha), K-56 (7.20 t/ha), K-64 (7.80 t/ha), and K-89 (7.13 t/ha) showed positive responses. Over an average of three years, it was remarkable that samples K-100, K-74, and K-64 proved resistant to stress conditions, showing greater stability with low yield variability, while the samples K-7, K-13, K-46, and K-89 had medium stability.

During three years of research, the study of wheat samples' environmental plasticity indicators (bi) and stability coefficient (Si^2) also occurred. The samples' yield showed different adaptive properties under the influence of environmental conditions. It was prominent that the variability of genotypes K-64 (bi = 0.5, Si^2 = 1.8), K-74 (bi = 0.7, Si^2 = 1.9), and K-100 (bi = 0.4, Si^2 = 0.9) was relatively low, indicating their resistance to stressful conditions. However, the wheat genotypes K-8 (bi = 5.6, Si^2 = 10.5), K-13 (bi = 2.7, Si^2 = 27.7), K-20 (bi = 5.8, Si^2 = 120.0), K-21 (bi = 3.4, Si^2 = 34.7), and K-41 (bi = 4.0, Si^2 = 10.1) bore ratings with the highest level of environmental ductility and stability (Table 1).

The analysis of relationships between quantitative and physiological indicators of selected samples, the correlation of the physiological properties of samples under high temperature and water deficiency stress, during the ripening of wheat grains, with quantitative traits ensuring yield transpired. In the scrutiny of samples' leaf surface, the average annual indicator for the leaf surface for wheat collection was 63.6 ± 6.42 cm (Table 2). The lowest indicator emerged in sample K-

8 (50.1 ± 1.98), while the highest was in sample K-64 (73.0 ± 7.36). Nine wheat samples showed above-average and the highest rate compared with the sample's average. Samples K-60, K-56, and K-89 differed in leaf length (29.2 ± 1.64, 28.1 ± 2.20, and 30.0 ± 0.80 cm, respectively), but were low in leaf width. In contrast, in sample K-21, the leaf length (28.3 ± 1.30) was relatively short, and the higher leaf width (2.48 ± 0.10) increased the leaf surface (69.9 ± 2.35). In these studies, the grain yield was also higher in samples with larger leaf areas. It was distinct that the samples with a leaf surface of above 70 cm^2 showed varied yields (6.5–7.7 t/ha) and 1000-grain weight (45–50 g) (Table 2).

Table 2. Variations in total biomass of wheat germplasm based on the traits leaf area and plant height.

Catalog number	Total biomass (kg)			Means ± SE (kg)	Total leaf area (cm^2)			Mean ± SE (cm)	Plant height (cm)			Means ± SE (cm)
	2017	2018	2019		2017	2018	2019		2017	2018	2019	
7	2.44	1.27	1.67	1.79±0.34	68.1	82.9	62.7	71.2±6.06	95.0	76.7	93.9	88.5±5.93
8	1.89	1.28	2.35	1.84±0.31	52.3	52.0	46.2	50.1±1.98	80.7	88.8	91.6	87.0±3.29
13	2.45	1.41	2.18	2.02±0.31	68.6	75.6	74.3	72.4±2.03	99.5	89.9	92.0	93.8±5.07
20	1.78	1.82	2.12	1.91±0.11	73.2	77.3	58.4	69.6±4.75	88.0	88.5	87.2	87.9±0.40
21	2.1	1.98	1.86	1.98±0.07	68.0	74.5	67.1	69.9±2.35	90.3	91.9	91.1	91.0±0.44
32	2.28	1.61	2.01	1.97±0.20	65.9	70.4	56.4	64.2±4.13	91.7	86.9	89.3	89.2±3.35
41	1.63	1.32	1.14	1.37±0.14	65.6	46.7	59.9	57.4±5.57	99.9	88.4	93.3	93.8±3.35
46	2.36	1.86	1.91	2.05±0.16	61.4	61.2	61.7	61.4±10.4	98.3	88.3	91.6	92.7±2.95
47	1.17	1.59	1.65	1.47±0.15	81.6	43.9	63.5	62.9±10.8	89.0	88.6	93.3	90.2±1.51
49	1.83	1.94	1.64	1.80±0.09	63.2	44.9	71.3	59.8±7.12	89.3	90.0	87.2	88.8±0.84
56	1.99	1.83	2.04	1.95±0.06	70.4	76.7	45.2	64.1±9.58	87.3	95.2	88.3	90.2±2.47
60	2.08	2.19	1.6	1.96±0.18	71.0	48.4	72.5	63.9±4.72	92.7	85.0	94.4	90.7±2.90
61	1.6	1.36	1.25	1.40±0.10	58.4	53.4	56.3	56.0±3.92	105.0	85.5	94.7	95.0±5.64
64	2.62	3.11	2.39	2.70±0.21	75.2	71.0	72.9	73.0±7.36	95.2	93.3	101.1	96.5±2.34
74	2.27	1.17	1.66	1.70±0.32	65.6	63.1	72.9	67.2±8.44	95.1	83.3	92.8	90.4±3.60
80	2.14	1.23	1.41	1.59±0.28	69.4	73.8	75.2	72.8±1.74	92.7	86.7	90.2	89.8±1.74
81	2.03	1.49	1.85	1.79±0.16	76.1	46.5	48.9	57.1±9.51	89.3	91.7	91.1	90.6±0.70
82	2.06	0.92	1.26	1.41±0.34	73.8	72.4	68.5	71.6±3.18	96.7	91.7	92.7	93.6±1.52
89	2.36	1.39	1.92	1.89±0.28	55.7	60.2	67.6	61.2±5.87	95.0	81.7	88.3	88.3±3.85
100	1.87	1.28	1.49	1.55±0.18	61.6	42.6	61.3	55.1±5.97	95.0	86.7	96.6	92.7±3.08
Means ± SE	2.05	1.60	1.77	1.81±0.20	67.35	61.19	62.3	63.6±6.42	93.3	87.9	92.0	91.5±0.53
Krasnodar 99	1.65	1.48	1.69	1.60±0.27	73.3	57.9	63.5	64.9±5.97	92.3	91.7	90.5	91.0±2.54
Weather information												
Atmospheric humidity (%)	59.6%	54.6%		68.6%	59.6%	54.6%		68.6		59.6%	54.6%	68.6%
Temperature (°C)	15	16.1		15.8	15	16.1		15.8		15	16.1	15.8

The relationship between indicators of leaf surface, plant growth, and biomass, and by analyzing the interaction of leaf moisture, plant growth, and biomass of samples based on the three-year analysis, the established total biomass of samples was 1.81 ± 0.20 kg/m^2. It exceeds the standard cultivar Krasnodar-99 (1.60 ± 0.27 kg/m^2). However, no significant differences appeared between the collected wheat samples and the standard cultivar Krasnodar-99 for the traits total leaf surface and plant height.

The dependence of the chlorophyll content in the studied samples with environmental influence has established that the three-year average chlorophyll content in the wheat samples was 2.63 ± 0.26 mg, while the standard cultivar Krasnodarskaya-99 was 2.34 ± 0.12. Overall, 0.29 mg more synthesized chlorophyll resulted in the studied wheat samples. It was also noteworthy that 85% of wheat samples had the total chlorophyll content of more than 2.50 mg, the leaf surface above 60 cm^2, and the grain yield above 6.0 t/ha. In samples K-7, K-46, K-13, and K-64, the highest values manifested for the chlorophyll, productivity, and leaf area, as well as, the daily net productivity of photosynthesis (Figure 2).

By determining the relationship between the various traits, it revealed total chlorophyll had a significant strong positive correlation with carotenoids (r = 0.94***) and a medium positive relationship with leaf surface (r = 0.54*). Likewise, it had a strong positive relationship with yield (r = 0.95***) and an average positive relationship with the daily net productivity of photosynthesis.

The red dots on the graph represent the predicted increase in grain yield, and the blue dots represent the total amount of chlorophyll in the regression analysis. The regression coefficient on the graph was 0.0082%, as shown by the equation y = 0.0082 × -2.88 (Figure 1). Fertility emerged to rise by 0.0082 g/m2 (up to 12%) when the total amount of chlorophyll increased by 1 mg/g. The three-year average chlorophyll content in the examined samples decreased from 3.34 to 2.03 mg/g when compared with the net photosynthetic productivity and crop output. Additionally, wheat samples with lower chlorophyll content showed a notable decline in grain yield.

The accumulation of dry matter in bread wheat is one of the vital parameters determining photosynthetic productivity and grain yield. In the three-year studies, the overall average photosynthetic productivity of the samples was 5.34 g/m^2/day. For the standard cultivar Krasnodarskaya-99, the daily productivity of photosynthesis was 5.47 g/m^2/day, which was higher than in the collection samples. In germplasm with net photosynthetic productivity above 6 g/m2/day, an increase in yield was up to 7.0 t/ha, and the total leaf surface was up to 71 cm^2 (except for sample K-46). Moreover, the dry matter accumulation level was up to 2.34 mg, and the total chlorophyll content ranged from 2. 62 to 3.34 mg.

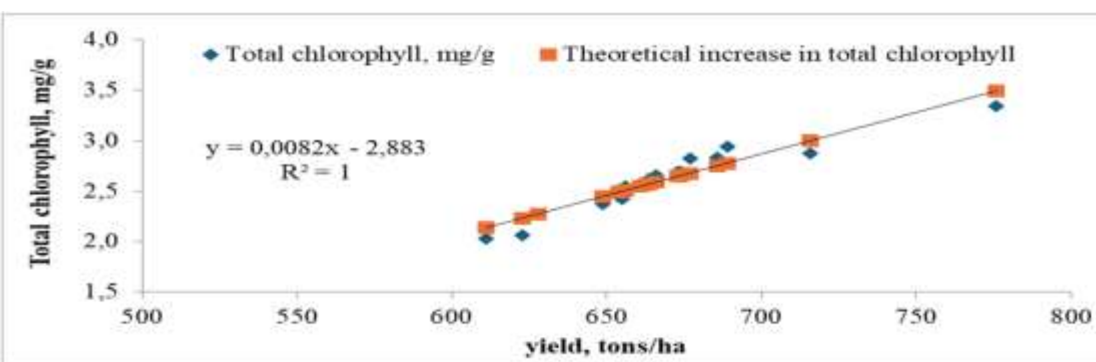

Figure 1. Effect of total chlorophyll on the grain yield of wheat germplasm.

By studying the influence of wheat samples on the photosynthesis, chlorophyll, and grain yield, it was prominent that the grain yield increased in samples K-7 (6.25 ± 0.35), K-13 (6.36 ± 0.56), K-46 (6.39 ± 0.62), and K-64 (6.48 ± 0.62) having the highest daily net productivity of photosynthesis. The remaining samples did not differ significantly from each other. In samples with net photosynthetic productivity of more than 6 $g/m^2/day$, the 1000-grain weight was 47.7 g, and the number of spikelets per spike was 17. Furthermore, the spike's length was 10.6 cm, the grain weight per spike was 2.23 g, and the grains per spike were 47.1, causing the spike weight to be more than 3.1 g (Table 3).

The results further revealed photosynthetic productivity provided a significant positive correlation with total leaf surface (*r* = 0.82***), an average positive linkage with total chlorophyll (*r* = 0.59**), an average positive relation with dry matter accumulation (*r* = 0.59**), and the grain yield (*r* = 0.69**). However, the ear length (*r* = 0.43*), number of grains (*r* = 0.46*), and the spike weight (*r* = 0.44*) showed a weak positive association with photosynthetic productivity.

Table 3. Variations in three-year chlorophyll content (mg/g) in wheat germplasm.

Catalog number	Total chlorophyll "a+6"			Mean± SE (mg/g)	Carotenoid content (mg/g)	Total leaf areas (cm^2)	Grain yield (t/ha)	Net productivity of photosynthesis (g/m^2day)
	2017	2018	2019					
7	3.34±0.06	3.09±0.20	2.99±0.06	3.14±0.51	2.02±0.07	71.2±6.06	7.07±3.15	6.25±0.35
8	2.87±0.24	2.53±0.13	2.24±0.30	2.55±0.18	1.68±0.09	50.1±1.98	6.56±7.16	4.26±0.37
13	2.95±0.03	1.95±0.05	3.71±0.04	2.87±0.11	1.87±0.31	72.4±2.03	7.16±4.29	6.36±0.56
20	2.20±0.48	2.15±0.09	3.01±0.20	2.45±0.28	1.74±0.17	69.6±4.75	6.54±6.98	4.89±0.39
21	2.37±0.06	3.40±0.49	2.21±0.26	2.66±0.37	1.65±0.15	69.9±2.35	6.66±3.86	5.21±0.37
32	2.34±0.08	2.25±0.59	3.89±0.26	2.82±0.53	1.90±0.37	64.2±4.13	6.77±4.02	5.47±0.28
41	1.93±0.02	2.60±0.29	2.29±0.36	2.27±0.20	1.53±0.09	57.4±5.57	6.28±5.28	4.80±0.43
46	2.83±0.49	2.92±0.15	3.08±0.11	2.94±0.08	2.06±0.05	61.4±10.4	6.89±2.86	6.39±0.62
47	2.01±0.44	2.21±0.26	1.95±0.05	2.06±0.08	1.40±0.09	62.9±10.8	6.23±4.17	4.75±0.65
49	2.17±0.09	3.01±0.20	1.95±0.14	2.37±0.32	1.62±0.21	59.8±7.12	6.49±4.13	4.75±0.54
56	2.81±0.22	2.31±0.47	2.60±0.29	2.57±0.15	1.66±0.07	64.1±9.58	6.61±5.55	5.12±0.33
60	2.29±0.24	2.52±0.10	3.14±0.34	2.65±0.25	1.83±0.18	63.9±4.72	6.66±3.09	5.53±0.22
61	1.91±0.13	1.77±0.31	2.41±0.02	2.03±0.19	1.41±0.13	56.0±3.92	6.11±1.84	4.56±0.43
64	3.56±0.22	3.28±0.19	3.19±0.72	3.34±0.11	2.18±0.04	73.0±7.36	7.76±1.63	6.48±0.62
74	3.59±0.07	2.15±0.29	2.33±0.08	2.69±0.45	1.83±0.30	67.2±8.44	6.74±8.01	5.54±0.21
80	3.00±0.23	2.53±0.38	2.53±0.14	2.69±0.16	1.96±0.26	72.8±1.74	6.73±2.45	5.31±0.65
81	2.23±0.05	2.99±0.06	2.52±0.22	2.58±0.22	1.66±0.14	57.1±9.51	6.63±3.93	5.11±0.43
82	2.21±0.09	3.14±0.56	2.53±0.14	2.62±0.27	1.73±0.26	71.6±3.18	6.64±3.26	5.21±0.75
89	2.44±0.56	2.83±0.10	3.23±0.15	2.83±0.23	1.88±0.15	61.2±5.87	6.86±1.54	5.75±1.31
100	1.88±0.44	2.23±0.21	3.28±0.19	2.46±0.42	1.61±0.28	55.1±5.97	6.55±1.07	5.04±0.40
$\bar{x} \pm S\bar{x}$	2.54±0.06	2.59±0.25	2.75±0.03	2.63±0.26	1.76±0.17	63.6±6.42	6.69±3.46	5.34±0.45
Krasnodar 99	2.16±0.19	2.33±0.22	2.56±0.13	2.34±0.12	1.60±0.05	64.9±5.97	6.30±1.20	5.47±0.66
Correlation between traits: r = 0.94***, r = 0.54*, r = 0.95***, r = 0.59**								

Note: Significant at P < 0.05* and P < 0.01**

DISCUSSION

The study analyzed the influence of climate change on the morphological, physiological, and productive characteristics of wheat germplasm. It was an effective way to consider these resistance features by adapting to the highest temperature and water deficit conditions observed during the grain maturity period (Agarwal *et al*., 2021). In the presented studies, productivity varied depending on the hydrothermal coefficient of the year (Table 1). The same results have also appeared in the other past studies in wheat (Zhang *et al*., 2020; Banihashemi *et al*., 2021). Under stressful conditions during 2018, the promising wheat genotypes' selection and isolation materialized. Some wheat samples showed the highest grain yield even under unfavorable environmental conditions (Ij = -2.8). This may be due to the positive effect of the plant cell on influencing those factors.

Stable cell hemostasis explains morphological and physiological processes. When compared with other samples, the wheat genotypes K-64 (bi = 0.5, Si2 = 1.8), K-74 (bi = 0.7, Si2 = 1.9), and K-100 (bi = 0.4, Si2 = 0.9) displayed the topmost values for stability and adaptability (Table 1). Previous research has demonstrated the beneficial and long-lasting effects of choosing high-yielding wheat cultivars under stressful circumstances (Mathew *et al*., 2019). These findings could infer the development of high-yielding wheat genotypes with favorable morphophysiological traits under stressful circumstances (Farhad *et al*., 2023). In another study, genotypic adaptation led to 10.78 t/ha improvements in grain yield (Grobovets and Fomenka, 2023).

In the studies, a positive correlation between leaf area and grain yield (r = 0.58) emerged, resulting in increased yield under strained conditions (Table 2). Past studies exhibited the ripening period (r = 0.52) and biological yield (r = 0.44*) have a positive effect on wheat grain yield under stressful conditions (Kumar *et al*., 2023). The morphological, physiological, and productive components of wheat samples during 2019 were notable with higher values. The reason for this can refer to the fact that the environmental index for the said crop season was equal to Ij = 0.69.

Genotypes by environment interactions under environmental stress, genotypic, and phenotypic indicators of cultivars underwent analysis as a model reflecting the influence of the reaction on wheat productivity (Esaulko *et al*., 2023). The environment at a relatively optimal level positively affected morphological characteristics in wheat. In samples with high biomass, higher leaf area and plant height were visible, which also positively altered productivity (Table 2). Plant height can considerably be one of the indicators characterizing the ecological plasticity of genotypes by varied soil and climatic conditions (Ripberger *et al*., 2015).

The superior total chlorophyll content, leaf area, and daily photosynthetic productivity in wheat genotypes K-7, K-46, K-13, and K-64 led to increased productivity (Table 2). It was further remarkable for the genotype grain yield with a leaf surface of more than 70 cm^2 was 6.5–7.7 t/ha, and the 1000-grain weight was 45–50 g. Past investigations revealed when the chlorophyll decreased by 16%–11% and the plant height, ear length, and spikelets per year by 26%, 9%, and 23%, respectively, the synthesis of proline and total soluble sugar increased by 28% and 6% (Tefera *et al*., 2021; Dubekova *et al*., 2023). Based on the results, it was evident that a positive relationship between the leaf area and productivity existed.

The results indicated a positive relationship (r = 0.58) between leaf area and grain yield and a weak positive relationship (r = 0.29) between 1000 grain weight and grain yield. Past findings enunciated that increasing leaf area also enhances the photosynthesis' productivity and, as a result, the grain yield rises (Zhao *et al*., 2018; Meliev *et al*., 2023). Notably, the total chlorophyll content in the wheat samples was high (2.50 mg) with a leaf area of 60 cm^2, and the grain yield exceeded 6.0 t/ha in 85% of the samples. In wheat genotypes K-7, K-46, K-13, and K-64, the maximum values were evident for the chlorophyll, productivity, and leaf area, as well as, the daily net productivity of photosynthesis

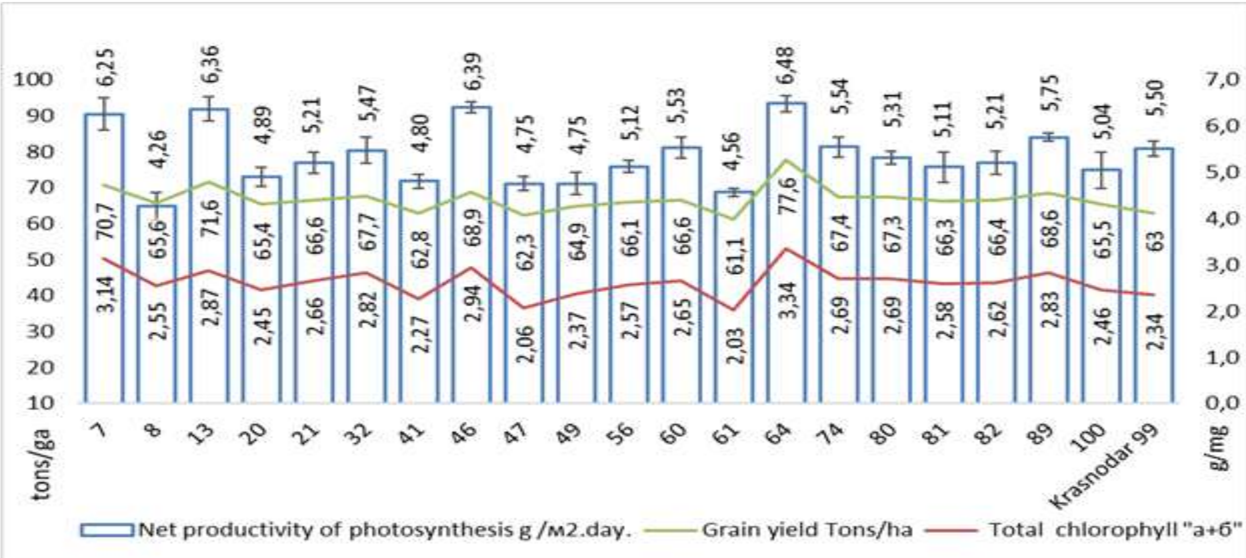

Figure 2. Effect of photosynthetic productivity on leaf area and grain yield of wheat gerplasm.

(Figure 2). Past studies have proven the positive influence of physiological characteristics on productivity (Yang *et al*., 2022).

CONCLUSIONS

Studying the influence of the genotype by environment interactions on the physiological and quantitative characteristics of the bread wheat germplasm in Uzbekistan, we arrived at the following conclusions. By analyzing the genotypes' influence, evidently, with the hydrothermal coefficient (Ij = 1.43) in 2017, the average grain yield was 6.84 t/ha, and in 2019, with Ij = 0.69, the yield was 8.77 t/ha. Wheat genotypes K-64 (bi = 0.5, Si2 = 1.8), K-74 (bi = 0.7, Si2 = 1.9), and K-100 (bi = 0.4, Si2 = 0.9) were distinct, based on the indicators of environmental plasticity (bi) and stability coefficient (Si2).

ACKNOWLEDGMENTS

The authors are grateful to researchers at the Institute of Genetics and Plant Experimental Biology and the Laboratory of Ecological Genetics and Plant Physiology, Academy of Sciences, Uzbekistan.

REFERENCES

Agarwal VP, Gupta NK, Gupta S, Singh G (2021). Screening of wheat germplasm for terminal heat tolerance under hyper-arid conditions. *Cereal Res. Commun.* 49: 375–383. http://doi.org/10.1007/s42976-020-00116-y.

Azimov A, Shavkiev J, Saidjanov S, Ziyaev Z, Valiyev L (2024). Mung Bean (*Vigna radiata* L.) genotypes assessment for drought tolerance in Uzbekistan. *J. Wildlife Biodivers*. 8(1): 65–75.

Baboeva SS, Matkarimov FI, Usmanov RM, Turaev OS, Togaeva MA, Baboev SK, Kushanov FN (2023). Climate change impact on chlorophyll content and grain yield of bread wheat (*Triticum aestivum* L.). *SABRAO J. Breed. Genet.* 55(6): 1930–1940. http://doi.org/10.54910/sabrao2023.55.6.7.

Bakhodirov U, Baboev S, Meliev S, Matkarimov F (2021). Determination of genetic polymorphism of dn genes in wheat cultivars resistant to Russian wheat aphid (*Diuraphis anoxia*). *Plant Cell Biotechnol. Mol. Biol.* 22 (3-4): 127–133.

Banihashemi SM, Eslamian SS, Nazari B (2021). The impact of climate change on wheat, barley, and maize growth indices in NearFuture and FarFuture periods in Qazvin Plain, Iran. *Int. J. Plant Prod.* 15: 45–60.

Chandio AA, Dash DP, Nathaniel SP, Sargani GR, Jiang YS (2023). Mitigation pathways towards climate change: Modelling the impact of climatological factors on wheat production in top six regions of China. *Ecol. Model.* 481:110381. http://doi.org/10.1016/ j.ecolmodel.2023.110381.

Climate change: Agriculture and livestock farming production require innovation. National News Agency of Uzbekistan. 02/27/2024. https://uza.uz/posts/571956.

Dubekova S, Sarbaev A, Yessimbekova M, Morgounov A, Yesserkenov A (2023). Winter wheat resistance to yellow rust in Southeast Kazakhstan. *SABRAO J. Breed. Genet*. 55(6): 1910-1919. http://doi.org/10.54910/sabrao2023.55.6.5.

Esaulko A, Sitnikov V, Pismennaya E, Vlasova O, Golosnoi E, Ozheredova A, Ivolga A, Erokhin V. (2023). Productivity of winter wheat cultivated by direct seeding: Measuring the effect of hydrothermal coefficient in the arid zone of Central Fore-Caucasus. *Agriculture.* 13: 55. https://doi.org/10.3390/ agriculture13010055.

Farhad M, Kumar U, Tomar V, Bhati PK, Krishnan JN, Kishowar-E-Mustarin, Barek V, Brestic M, Hossain A (2023). Heat stress in wheat: A global challenge to feed billions in the current era of the changing climate. *Front. Sustain. Food Syst.* 7:1–24. https://doi. org/10.3389/fsufs.2023.1203721.

Fujino K, Hirayama Y, Kaji R (2019). Marker-assisted selection in rice breeding programs in Hokkaido. *Breed. Sci*. 69:383–392. https://doi. org/10.1270/jsbbs.19062.

Grobovets AI, Fomenka MA (2023). Climate change and features of selection of winter bread wheat for productivity and adaptability to it. *Bulletin of Russian Agricul. Scie.* 1:20–25. https://doi.org/10.31857/2500-2082/2023/ 1/20-25).

Grogan SM (2016). Phenotypic plasticity of winter wheat heading date and grain yield across the US Great Plains. *Crop Sci.* 56:2223–2236.

Kumar H, Chugh V, Kumar M, Gupta V, Prasad S, Kumar S, Singh CM, Kumar R, Singh BK, Panwar G, Kumar M (2023). Investigating the impact of terminal heat stress on contrasting wheat cultivars: A comprehensive analysis of phenological, physiological, and biochemical traits. *Front. Plant Sci* 14:1–17. https://doi. org/10.3389/fpls.2023.1189005.

Kumar RR, Ahuja S, Rai GK, Kumar S, Mishra D, Kumar SN, Rai A, Singh B, Chinnusamy V, Praveen S (2022). Silicon triggers the signalling molecules and stress-associated genes to alleviate the adverse effect of terminal heat stress in wheat with improved grain quality. *Acta Physiol. Plant.* 44:30. https://doi. org/10.1007/s11738-022-03365-y.

Lves F, Schmidt L (2022). Editorial: Climate change and society. *Front. Sociol.* 7:991193. https://doi. org/10.3389/fsoc.2022.991193.

Mathew I, Shimelis H, Mutema M, Clulow A, Zengeni, R, Mbava N, Singh B, Chinnusamy V, Praveen S (2019). Selection of wheat genotypes for biomass allocation to improve drought tolerance and carbon sequestration into soils. *J. Agron. Crop Sci.* 205: 385–400. https://doi. org/10.1111/jac.12332.

Meliev S, Chinniqulov B, Aytenov I, Isoqulov S, Ochilov B, Shokirova D, Murodova S, Dolimov A, Turakulov Kh, Bozorov T, Baboev S (2023). Characterization of CIMMYT bread wheat germplasm for resistance to yellow rust and environmental factors. *SABRAO J. Breed. Genet*. 55(6): 1865-1877. http://doi.org/10.54910/sabrao2023.55.6.1.

Meliev SK, Turakulov XS, Bozorov TA, Melikuziev FA, Asranova MK, Buzrukov SS (2023b). Impact of climate change on wheat productivity. *Biological. Sci. Kazakhstan* 1:34–40. https://doi. org/10.52301/1684-940X-2023-1-34-40.

OECD – FAO. Agricultural Outlook 2018–2027. Chapter 3: Cereals. Rome: Food and Agriculture Organization of the United Nations. 10:1091–1098.

Prysiazhniuk LM, Topchii OV, Dymytrov SH, Kyienko ZB, Chernii SO (2020). Estimation of adaptive potential of varieties of spring rape (*Brassica napus* L.) in different soil climatic zones of Ukraine. *Plant. Var. Studying and Prot*. 16(2): 144–153.

Ripberger NA, Baume D, Trautz G (2015). Variability of plant heights of hybrid forms of spring bread wheat (*Triticum aestivum* L.) as a way of their adaptation in different ecological and geographical conditions. *Vavilov J. Breed. Genet.*19 (2): 185–190.

Sabri RS, Rafii MY, Ismail MR, Yusuff O, Chukwu SC, Hasan N (2020). Assessment of agro-morphologic performance, genetic parameters and clustering pattern of newly developed blast resistant rice lines tested in four environments. *Agro.* 10(8):1098. https://doi.org/10.3390/agronomy10081098.

Tefera A, Kebede M, Tadesse K, Getahun T (2021). Morphological, physiological, and biochemical characterization of drought-tolerant wheat (*Triticum* spp.) varieties. *Inter. J. Agro.* 5:1–12.

Yang B, Wen X, Wen H, Feng Y, Zhao J, Wu B, Zheng X, Yang C, Yang S, Qiao L, Zheng J (2022). Identification of genetic loci affecting flag leaf chlorophyll in wheat grown under different water regimes*. Front. Genet.* 13:832898. https://doi.org/10.3389/fgene. 2022.832898.

Zhang X, Du X, Hong J, Du Z, Lu X, Wang X (2020). Effects of climate change on the growing season of alpine grassland in Northern Tibet, China. *Glob. Eco. Conser.* 23: 1–12.

Zhao C, Bao Y, Wang X, Yu H, Ding A, Guan C, Cui J, Wu Y, Sun H, Li X (2018). QTL for flag leaf size and their influence on yield-related traits in wheat. *Euphytica.* 214: 1–15..