RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (6) 1865-1877, 2023
http://doi.org/10.54910/sabrao2023.55.6.1
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

CHARACTERIZATION OF CIMMYT BREAD WHEAT GERMPLASM FOR RESISTANCE TO YELLOW RUST AND ENVIRONMENTAL FACTORS

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SUMMARY

One of the major tasks faced by wheat breeders in Uzbekistan is to enhance wheat genotypes' adaptability to soil and other environmental conditions and improve the grain quality, making the country self-sufficient in wheat grains and later becoming an exporter. Better results are achievable using the world wheat collection, including the CIMMYT germplasm. Determination of the positive correlation of physiological traits of new wheat cultivars, the importance of physiological indicators of water balance with productivity, and the vital role of these indicators in productivity level were the chief concerns. The timely study evaluated heat resilience, rust resistance, and grain yield in bread wheat genotypes. Bread wheat germplasm obtained from CIMMYT with a background of artificial infection of yellow rust incurred scrutiny for their rust resistance. A 15% incidence was detectable in seven genotypes; however, necrosis quickly formed around the symptoms of the disease in plant leaves, preventing its further development. Resistant wheat accessions, i.e., 1088, 1164 (R), 1006, and 1251 (MR), occurred as moderately resistant, showing high leaf area and grain yield. The average value of the genotypes was low, mainly due to the two rust-resistant samples, and the 1000-grain weight was 34.8 g and 34.6 g, respectively, and the grains per spike and grain yield were lower than the average. The chlorophyll a and b, total chlorophyll, carotenoid content, relative water content, flag leaf area, and production traits of the genotypes K-1088 and K-1164 gained assessment, revealed to be physiologically effective under the field conditions of Tashkent, Uzbekistan. Quantitative indicators of the productivity of these wheat genotypes indicated positive differentiation. Selection ensued for promising accessions to develop initial sources for producing the wheat genotypes with rust resistance and high grain yield under the environmental conditions of Uzbekistan.

Communicating Editor: Dr. Himmah Rustiami

Manuscript received: July 12, 2023; Accepted: September 18, 2023.

Citation: 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.

Keywords: Bread wheat (*T. aestivum* L.)*,* wheat yellow rust, rust resistance, heat tolerance, leaf area, chlorophyll a and b, carotenoid, water content, grain yield

Key findings: By comparing with the standard check, a lower average value of the wheat accessions was mainly due to the two rust-resistant genotypes, K-1164 and K-1289, which also have 1000-grain weights of 36.1 g and 34.8 g, respectively. The grain yield of these genotypes was also much lower than the average yield. Desirable chlorophyll a and b, total chlorophyll and carotenoid content, relative water content, leaf area of flag leaves, and higher grain yield were substantial in the wheat landraces K-1088, K-1082, and K-1164 and proved to be physiologically effective under environmental conditions of Tashkent, Uzbekistan. Quantitative indicators of the productivity of these accessions provided positive differentiation, with these genotypes recording higher values than the rest of the entries.

INTRODUCTION

The world's population grows daily; therefore, it is necessary to provide environmentally safe and healthy food to humankind (Vicente-Serrano *et al.,* 2013; Bakhodirov *et al.,* 2021). Agriculture is one of the main sectors in cultivating different crops, where wheat is vital. The wheat cultivars developed nowadays should be high-yielding, with valuable economic traits, resistance to yellow rust, and adverse environmental conditions. Assessing the future impacts of climate change on crop health and productivity has become the subject of several recent studies (Hatfield *et al.,* 2018). These findings have encouraged extensive efforts to formulate the effects of future climate and also authenticate the continual temperature rise will depress wheat yields by 6% per single degree of increase (Asseng *et al.,* 2015). The climate change impact quantification on wheat crops is crucial to developing well-adaptive wheat genotypes in the future and improving crop models (Hussain *et al.,* 2018).

The biotic and abiotic stress conditions, including yellow rust and heat stress, caused adverse effects on bread wheat production, particularly under unexpected climate changes (Kamara *et al.,* 2021; Eman *et al.,* 2022). Therefore, by selecting practical breeding materials for establishing an operative basis for deciphering the mechanisms of heat stress and yellow rust tolerance, it is necessary to subject the different wheat genotypes to the full use of the physiological potential under water-deficit conditions.

Yellow rust, caused by the fungus *Puccinia striiformis* f.sp. tritici is the most devastating bread wheat disease that triggers considerable destruction in various regions worldwide, threatening its production. The host genetic resistance to yellow rust is the only way and most economical and environmental approach to control this disease with no additional costs (Feng *et al.,* 2018; Eman *et al.,* 2022). Climate change factors also considerably affect rust infection. Wheat rust diseases mainly incur influences from relative humidity, temperature (minimum and maximum), rainfall, and wind speed. Early sowing is critical in avoiding rust severity, while more severe infections occur in the wheat crop with late sowing. Late sowing induces heat stress, especially during the grain-filling period, thus differentiating sensitive and tolerant wheat genotypes (Eman *et al.,* 2022).

High temperatures and drought stress are the usual constraints during the grain-filling stage of wheat. The recent climate extremes, including high temperatures, are projecting deleterious impacts on wheat growth, development, and productivity (Sandro *et al*., 2022). Terminal heat stress at the post-heading stage causes considerable yield reduction due to stress at the critical stages like anthesis and grain-filling (Elbasyoni, 2018; Shavkiev *et al.,* 2022; Kurbanbaev *et al*., 2023). It accelerates chlorophyll degradation in photosynthetic organs, such as leaves, consequently decreases the photosynthetic rate and efficiency (Yang *et al.,* 2016a). Hence, a lower fixation and assimilation of CO_2 leads to restricted dry matter accumulation and grain development (Hamlyn and Jones, 2007; Yang *et al.,* 2016b). Therefore, leaf chlorophyll verifies to be resistant to drought and high-temperature stress in wheat (Farooq *et al.,* 2014; Barakat *et al.,* 2015). Under abiotic stress situations, such as, drought, high temperature, salinization, and heavy metal presence, genotypes with higher chlorophyll content maintain higher photosynthetic capacity that helps maintain a higher yield (Awlachew *et al.,* 2016; Gupta *et al.,* 2020; Bhoite *et al.,* 2021; Borjigin *et al.,* 2021).

Observations indicated that genotypes genetically similar in origin differ in the amount of chlorophyll depending on the external environment and growing conditions, and the response to external environmental influences is also different (Manuchehri and Salehi, 2014; Dymov and Golovko, 2019). Studies have scientifically proven that chloroplasts play an essential role in activating the signaling of cell stimulators under heat stress (Yuan *et al*., 2015). Identifying the genetic potential of grain crops results in the expression of physiological mechanisms and their implementation in the field (Abbasov and Rustamov, 2015). The opportune study aimed to evaluate the heat resilience, rust resistance, and grain yield in bread wheat germplasm under environmental conditions of Tashkent, Uzbekistan.

MATERIALS AND METHODS

Breeding material and experimental site

The conduct of the study commenced in 2017–2019 at the Tashkent Region of Uzbekistan (41.2322° N and 69.2754° E). The experiments ran at the Dormon Experimental Site, Institute of Genetics and Plant Experimental Biology, Academy of Sciences of Uzbekistan, Tashkent Region, Uzbekistan. Wheat lines planted in ring plots measured 5 m × 60 m × 10 m. By evaluating the physiological characteristics of the wheat accessions, more than 10 flag leaves from each line incurred analysis. The International Bread Wheat Selection Nursery (46th IBWSN) obtained from CIMMYT, Mexico, became the trial specimens, with cultivars Krasnodarskaya 99 as the local check in the experiments (Table 1).

Table 1. Origin and catalog numbers of CIMMYT cultivars.

Catalog numbers	Name of cultivars	Origin
1029	MILAN/S87230//BAV92*2/3/TECUE#1	Mexico
1030	WBLL1*2/VIVITSSI//AKURI/3/ WBLL1*2/BRAMBLING	Mexico
1033	TACUPETO 2001*2/KIRITATI// VILLAJUAREZ F200...	Mexico
1036	VILLA LUAREZ F 2009/CHYAK	Mexico
1045	FRET2*2/BRAMBLING//BECARD/3/ WBLL1*2/...	Mexico
1063	CHIBIA//PRLII/CM65531/3/SKAUZ/ BAV92/4/…	Mexico
1066	GAN/AE..SQUARROSA (408)//2*OASIS/5* BORL95/3/...	Mexico
1079	KIRITATI//ATILLA*2/PASTOR/3/AKURI	Mexico
1105	WBLL1//KAUZ/2*STAR/3/BAV92/ RAYON/4/…	Mexico
1158	WBLL1*/BRAMBLING//JUCHI/3/WBLL1*2/BRAMBLING	Mexico
1170	BABAX/LR42//BABAX*2/3/KUKUNA/4/ TAM 200/...	Mexico
1194	MUU/FRNCLN/...	Mexico
1204	PAURAQ/VILLA JUAREZ F2009	Mexico
1255	SAAR/WBLL1//QVAIV	Mexico
1264	PBW65/2*PASTOR*2//MUU	Mexico
1287	KACHU/BECARD//WBLL1*2/ BRAMBLING	Mexico
1289	PCALR/KINGBRID#1//KIRITATI/2* TRCH	Mexico
1291	PFAU/SERI.1B//AMAD/3/WAXWING*2/4/ BECARD	Mexico
1326	ND643//2*ATILLA*2/PASTOR /3/WBLL1*2/KURUKU/4/	Mexico
1327	SHORTENEDSR26TRANSLOCATION// WBLL1*2/...	Mexico
Krasnodarskaya-99		Russia

Meteorological conditions

Data on the weather conditions of District Kibray during 2017–2019 are available in Figure 1. In 2017, the average annual temperature was 14.7 °C, and the observed temperature was 15.5 °C, 0.8 °C higher than the average temperature. The average minimum temperature of February, March, April, May, June, and July was 11.4 °C, while the maximum temperature was 24.2 °C. It was noticeable that the highest temperature by month corresponds to June (34.6 °C) to July (37.5 °C), the periods of waxing and the full ripening of wheat. The average annual precipitation was 444.0 mm, and the observed precipitation was 435.4 mm, with a 9.6% observed increase compared with the average rainfall. By month, the highest downpour fell in February, the lowest was in July, and the hydrothermal coefficient (HTC) was 0.76 in 2017.

In 2018, the weather had changed. The annual average temperature was 14.7 °C, but the observed temperature was 15.2 °C, 0.5 °C higher than the average temperature, and the annual rainfall was 372 mm. Notably, the highest monthly rainfall was 71 mm in March, and the highest temperature was 38.4 °C in July. Compared to 2017, it was obvious that the precipitation and temperature were 15% and 1.93% lower, respectively. The HTC was 0.44 in 2018.

The annual average temperature was 14.7 °C in 2019, with the observed temperature of 15.7 ℃, 1.43 °C higher than the average temperature. The yearly average rainfall was 444 mm, and the observed precipitation was 328 mm, 26.2% less than the average. It was evident that the maximum rains (148 mm) emerged in April, and the highest temperature (38.9 °C) was in July. The HTC was 1.26 in 2019. Generally, a relatively favorable moisture level transpired in 2019, while dry conditions were prominent in 2017 and 2018.

The chlorophyll a and b, total chlorophyll, carotenoids in the wheat leaves, relative water content, and leaf area estimates also materialized. For all these traits, the samples used were the flag leaves in the main stalk of wheat plants in the field, calculating the amounts of the mentioned traits in the wheat genotype leaves (Lichtenthaler and Wellburn, 1985).

The leaf area determination used the Petiole program (Petiol APK - APKPure.com). The relative water content estimations employed the method according to Barrs and Weatherly (1962). In the experiment, 10 leaf discs collected randomly in each treatment underwent accurate weighing up to the third decimal on a single pan analytical balance, considered the fresh weight. Floating the weighed leaf discs on distilled water in a petri dish allowed them to absorb water for six hours. Afterward, the leaf discs' removal from the water continued to their surface, blotted gently, and weighed. It referred to the turgid weight. After drying in a hot air oven at 72 °C for 48 h, the dry weight recording continued with the relative water content (RWC) estimated according to Hamlyn and Jones (2007).

In wheat genotypes, the disease severity scoring ran two to three times in each experiment using the modified Cobb's scale (Peterson *et al.,* 1948), with the host response to infection determined according to Roelfs *et al.* (1992). Following standard procedures, the study collected data on the yield parameters of wheat. Counting the fertile tillers started at maturity from randomly selected sites (m^2) in each experimental unit and averaged (Sayre *et al.,* 1997). For analysis of variance (ANOVA), it continued in EXCEL 2016 and Stat View 5.0. Taking probability difference levels had the range of $0.05 < P < 0.0001$.

RESULTS

After studying the wheat germplasm, selecting the resistant and moderately resistant genotypes to yellow rust disease also had their data recorded on quantitative characteristics, such as, plant height, spikes per plant, the number of grains per spike, 1000-grain weight, biomass, and grain yield per m^2. Rust pathogens damage the foliage — the chief organ of photosynthesis — destroying seedlings, impairing growth, and interfering in

Table 2. Morphological indicators for various wheat landraces and standard cultivar.

Catalog number	Name of cultivars	Yellow rust	Lodging Resistant, point scale	Plant height (cm)
1029	MILAN/S87230//BAV92*2/3/TECUE#1	15R	8	95
1136	WBLL1*2/VIVITSSI//AKURI/3/ WBLL1*2/BRAMBLING	0/R	8	91
1125	TACUPETO 2001*2/KIRITATI// VILLAJUAREZ F200...	30MR	9	95
1036	VILLA LUAREZ F 2009/CHYAK	10R	9	85
1045	FRET2*2/BRAMBLING//BECARD/3/ WBLL1*2/...	10R	3	95
1063	CHIBIA//PRLII/CM65531/3/SKAUZ/ BAV92/4/…	15R	9	87
1066	GAN/AE..SQUARROSA (408)//2*OASIS/5* BORL95/3/...	0/R	4	85
1088	KIRITATI//ATILLA*2/PASTOR/3/AKURI	0/R	9	98
1105	WBLL1//KAUZ/2*STAR/3/BAV92/ RAYON/4/…	25MR	8	95
1158	WBLL1*/BRAMBLING//JUCHI/3/WBLL1*2/BRAMBLING	45 MS	8	95
1251	BABAX/LR42//BABAX*2/3/KUKUNA/4/ TAM 200/...	20/R	9	95
1131	MUU/FRNCLN/...	40 MR	3	95
1204	PAURAQ/VILLA JUAREZ F2009	15R	9	93
1255	SAAR/WBLL1//QVAIV	20MR	9	93
1164	PBW65/2*PASTOR*2//MUU	0/R	9	93
1006	KACHU/BECARD//WBLL1*2/ BRAMBLING	0/R	8	93
1289	PCALR/KINGBRID#1//KIRITATI/2* TRCH	10R	9	95
1296	PFAU/SERI.1B//AMAD/3/WAXWING*2/4/ BECARD	0/R	9	94
1082	ND643//2*ATILLA*2/PASTOR /3/WBLL1*2/KURUKU/4/	0/R	8	90
1327	SHORTENEDSR26TRANSLOCATION// WBLL1*2/...	60MS	8	90
Krasnodarskaya-99		5 MS	9	91

the metabolism process of the host plants. Management of any disease can begin with the correct identification of the pathogen.

It also hinders the pathogen's ability to mutate and multiply rapidly and its air-borne dispersal mechanism from one field to another and even over long distances. In the wheat germplasm, eight wheat accessions recognized as immune had no symptoms of rust disease, while seven landraces appeared with 10%–15% rust incidence; however, necrosis formation around the disease symptoms in the leaves stopped the rust disease from further developing. Although three samples were 20%–30% infected, later, these wheat genotypes developed necrosis and incurred a rating as moderately resistant (MR). In addition, two wheat genotypes earlier selected as moderately susceptible (MS) for testing in the control nursery, afterward, showed strong resistance to spring frosts despite being tolerably winter hardy.

The results further enunciated that CIMMYT wheat lines, viz., 1296, K-1289, K-1131, K-1125, K-1088, K-1251, K-1082, K-1136, K-1006, and K-1164, and the standard cultivar Krasnodarskaya-99 have shown reliable values and significant differences for chlorophyll a and b, total chlorophyll, carotenoid content in the leaves, relative water content, and leaf area. The highest rate of chlorophyll a arose in genotypes K-1088 and K-1164 and standard Krasnodarskaya-99 (2.54 ± 0.03, 2.26 ± 0.37, and 2.10 ± 0.21 mg/g, respectively), whereas lowest values of indicators appeared in accessions, K-1131 and K-1251 (1.36 ± 0.10 and 1.52 ± 0.19 mg/g, respectively) (Table-2). The genotypes K-1088, K-1164, K-1296, K-1136, and K-1088 showed with a higher chlorophyll a content compared with K-1296, K-1289, K-1131, K-1125, K-1251, and K-1006. The landraces K-1088 and K-1164 also showed reliable differences from the standard cultivar Krasnodarskaya-99.

The highest content of chlorophyll b materialized in the wheat genotypes K-1088, K-1082, and K-1136 (1.17 ± 0.01, 1.02 ± 0.01, and 1.02 ± 0.20 mg/g, correspondingly), showing at par with the standard cultivar Krasnodarskaya-99 (0.99 ± 0.10 mg/g). However, the lowest chlorophyll b content was evident in wheat genotype K-1131 (0.59 ±

0.04 mg/g). The chlorophyll b index of the wheat genotypes has reliable differentiation from results that the accession K-1088 had a higher content than the standard cultivar Krasnodarskaya-99, and the genotypes K-1131 and K-1082 had a lower chlorophyll b content than the check cultivar (Table-2).

The carotenoids content was the highest in the wheat genotype K-1088 (0.86 ± 0.07 mg/g) versus the standard cultivar Krasnodarskaya-99 (0.78 ± 0.19 mg/g); yet, the lowest indicator score occurred in the wheat landraces, i.e., K-1131, K-1251, K-1289, K-1125, and K-1006 (0.29 ± 0.09, 0.51 ± 0.18, 0.52 ± 0.08, 0.53 ± 0.14, and 0.51 ± 0.15 mg/g, respectively) (Table-2). The study also determined a reliable difference in the carotenoid content of wheat line K-1088 and the standard cultivar Krasnodarskaya-99, and the lowest indicator manifesting in the wheat accession K-1131 compared with the check.

The highest rate of total chlorophyll resulted in wheat accessions K-1088 and K-1082 (3.71 ± 0.15 and 3.24 ± 0.11 mg/g), followed by the standard cultivar Krasnodarskaya-99 (3.08 ± 0.16 mg/g), with the lowest index noted in wheat line K-1131 (1.95 ± 0.14 mg/g) (Table-2). The total chlorophyll content of the accession K-1088 differed from that of the standard cultivar, and the difference between the genotypes K-1131 and K-1251 compared with the benchmark cultivar Krasnodarskaya-99 showed reliability (Figure 1).

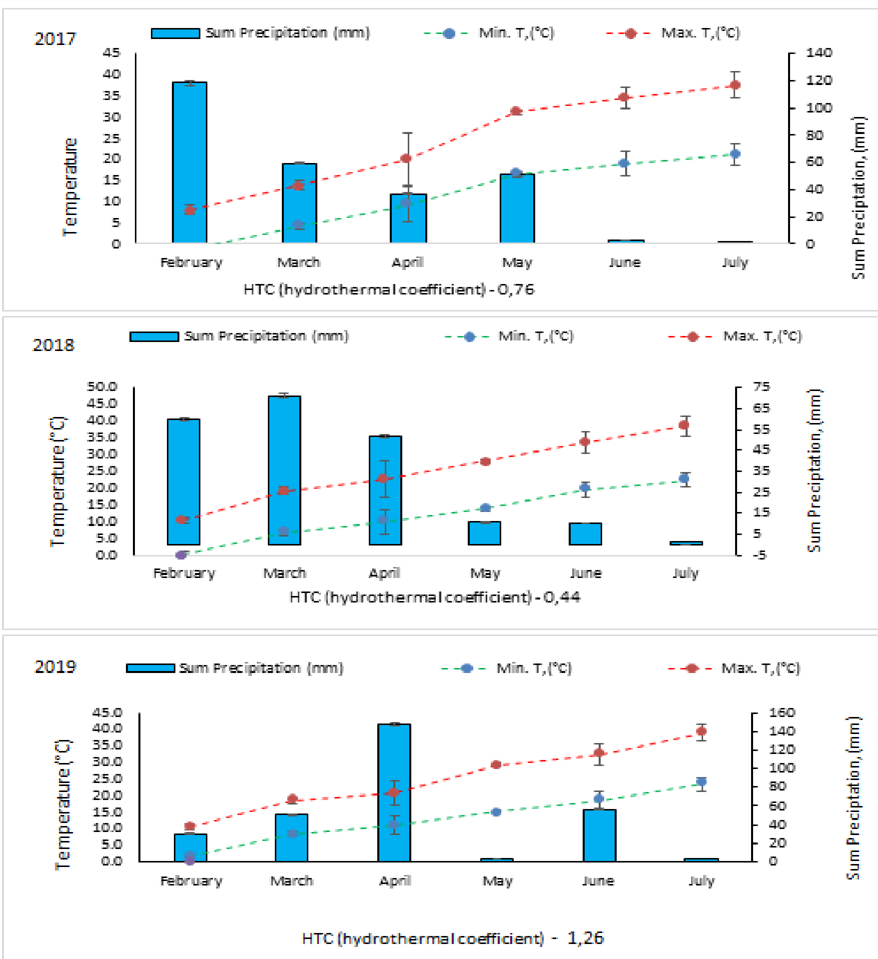

Figure 1. Monthly maximum and minimum temperatures and precipitation for 2017, 2018, and 2019 for the Tashkent Region of Uzbekistan. Centre for Hydro Meteorological Station at Tashkent, Kibray.

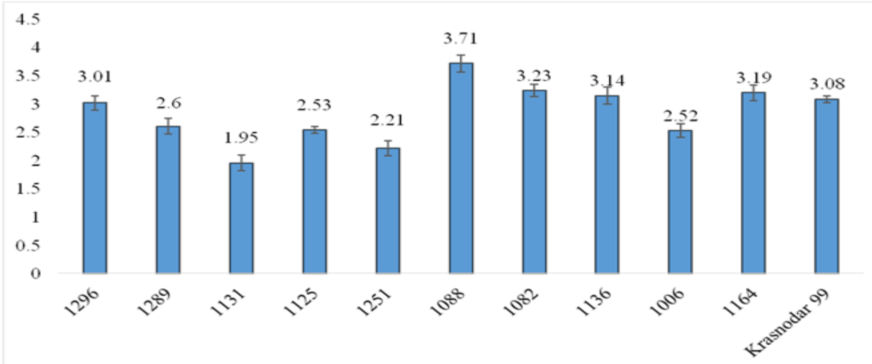

Figure 2. Amount of total chlorophyll (mg/g) on the leaves of wheat cultivars (2017–2019).

In this study, the chlorophyll a and b, the total chlorophyll, and carotenoid content of the wheat genotypes K-1088, R-1082, K-1136, and K-1164 were close to and even higher than the standard cultivar Krasnodarskaya-99. At the same time, the accession K-1131 showed a sharply lower content for the said traits than the check cultivar and other wheat lines. The genotypes K-1088, K-1164, and K-1082 of the CIMMYT collection proved to contain chlorophyll a and b, total chlorophyll, and carotenoids in superior amounts compared with the norm cultivar Krasnodarskaya-99 and other accessions of the germplasm. Leaf chlorophyll content (LCC) is a crucial variable that plays a vital role in photosynthesis and is positively associated with plant growth, development, and fertility. These results were in analogy with past findings (Croft *et al.,* 2017; Huang *et al.,* 2022). Therefore, wheat genotypes K-1088, K-1164, and K-1082 were the most effective for cultivation in the agriculture sector.

According to quantitative traits, the highest leaf area was visible in the accessions of wheat germplasm, i.e., K-1088, K-1251, and K-1006 (68.05% ± 2.05%, 62.6% ± 1.77%, and 67.87% ± 2.09%, respectively), followed by the standard wheat cultivar Krasnodarskaya-99 (61.54% ± 1.92%). However, the lowest leaf area emerged in wheat strains K-1131 and K-1125 (49.59% ± 1.20% and 37.32% ± 1.03%, respectively). A reliable difference in leaf area index was distinct in accessions K-1088 and K-1006 from the standard cultivar and wheat genotypes K-1131 and K-1125 cultivars (Figure 2). Past findings revealed a positive correlation among the indicators of water balance, productivity, and leaf surface (Parry *et al.,* 2011; Zhang *et al.,* 2009). The leaf area indicator was higher in wheat genotype K-1088 than the standard cultivar Krasnodarskaya-99 and all other landraces found in the wheat germplasm. The wheat accessions K-1125 and K-1131 differed reliably with their low values for the said parameter.

Significant differences occurred in the wheat accessions and the standard cultivar on the water content in the flag leaf indicator (Figure 3). During the analysis, the highest water content surfaced in the genotype K-1164 (71.5% ± 2.39%), followed by K-1082 (70.4% ± 2.15%), K-1088 (69.9% ± 2.42%), and K-1006 (69.0% ± 2.49%). However, the lowest rate of water content in leaves was evident in the wheat landrace K-1131 (61.4% ± 2.10%), followed by genotypes K-1296 (66.2% ± 2.10%); 1289, 1136, K-1125, and 1251 (up to 68.7% ± 2.43%) (Table 3). The standard wheat cultivar Krasnodarskaya-99 (69.1% ± 1.92%) and the accession K-1131 revealed no significant differences in the leaf water content. Water showed a positive connection with the growth and development of crop plants. The relevant results were consistent with past studies on RWC and leaf area in wheat (Meliev *et al.,* 2021). The findings suggested that promising landraces like K-1088, K-1082, and K-1164 should serve as valuable initial breeding material in further selection for better adaptation.

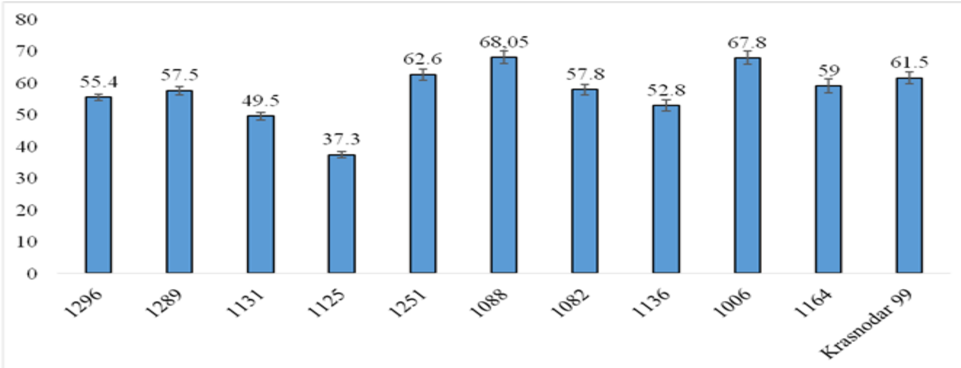

Figure 3. Flag leaf area (cm^2) of the wheat genotypes during 2017–2019.

Table 3. Physiological traits of the wheat landraces during 2017–2019.

Catalog number	Chl a (mg/g)	Chl b (mg/g)	Chl a + Chl b (mg/g)	Carotenoids (mg/g)	RWC (%)	LA (cm^2)
	χ±m	χ±m	χ±m	χ±m	χ±m	χ±m
1296	2.06±0.14	0.95±0.07	3.01±0.13	0.74±0.15	66.2±2.10	55.4±1.00
1289	1.79±0.20	0.82±0.09	2.60±0.14	0.52±0.08	66.6±2.99	57.5±1.35
1131	1.36±0.10	0.59±0.04	1.95±0.14	0.29±0.09	61.4±2.10	49.5±1.20
1125	1.71±0.08	0.82±0.06	2.53±0.16	0.53±0.14	68.7±2.43	37.3±1.03
1251	1.52±0.19	0.70±0.07	2.22±0.13	0.51±0.18	66.8±2.47	62.6±1.77
1088	2.54±0.03	1.17±0.01	3.71±0.15	0.86±0.07	69.9±2.42	68.0±2.05
1082	2.22±0.05	1.02±0.02	3.24±0.11	0.74±0.10	70.4±2.15	57.8±1.69
1136	2.12±0.35	1.02±0.20	3.14±0.15	0.73±0.38	67.4±2.95	52.8±1.76
1006	1.72±0.14	0.80±0.08	2.52±0.12	0.51±0.15	69.0±2.49	67.8±2.09
1164	2.26±0.37	0.93±0.35	3.19±0.14	0.74±0.34	71.5±2.39	59.0±2.13
Krasnodarskaya-99	2.10±0.21	0.99±0.10	3.08±0.16	0.78±0.19	69.1±1.92	61.5±1.92

Chl a and b: Leaf chlorophyll content a and b, Chl a + b: Total chlorophyll content, RWC: Relative water content, LA: Leaf area.

In the performed experiments, evaluating the wheat germplasm in comparison to the standard cultivar Krasnodarskaya-99 also ensued for yield parameters. It has become known that the valuable economic traits that ensure productivity vary and depend upon unfavorable environmental conditions (Poltoretskyi *et al.,* 2020). In the present era, modern cultivars should be productive and stable under different climatic conditions and high in plasticity (Kobylyansky and Solodukhina, 2013). According to the results presented in Table 4, the HI - productivity index describes the ratio of grain to total biomass; in the selected samples, this indicator was from 0.32 to 0.50, with the average value at 0.37. It is a definite good indicator, with 37% of the total biomass as grain. The second indicator was the grain yield per area, and based on 1 m^2, the average grain yield was 5.9–7.4 t/ha. The wheat accessions 1125 (6.8), 1289 (6.6), and 1006 (6.6) showed records of more than 65 t/ha. In the wheat germplasm, the Catalog numbers 1296, 1251, and 1082 indicated a grain yield of 61–65 t/ha, while accession 1136 yielded 59 t/ha.

The other polygenic parameters were biological yield and biomass, observed with varied values among the diverse wheat accessions and the standard check. However, the biomass was inversely related to the yield index, where the higher the yield index, the higher the biomass. In intensive wheat cultivars, the low-growing cultivars displayed a slight decrease in biomass; however, the biomass role in the synthesis of nutrients in

Table 4. Quantitative traits of the wheat genotypes during 2017–2019.

Catalog numbers	Name of cultivars	HI[1]	Grain yield (t/ha)	Biomass (g/m^2)	Number of spikes (m^2)	TKW (g)	Number of grains (m^2)	Number of grains per spike
1296	PCAFR/KINGRIBD#1/ /KIRITATI/2*TRCH	0.32	6.1	2066.4	295.2	46.4	14441.8	48.9
1289	CHIBIA\\PRLII\CM 65531\3\SW89,5181\KAUZ\4\,,,	0.34	6.6	1342.9	394.9	34.8	13120.6	33.2
1131	WBLL1*2/VIVITSI// MESIA/3/KIRITATI/WBLL1	0.50	6.8	1452.8	161.4	57.6	12779.2	79.2
1125	WHEAR*2/3/FRET2/ WBLL1//TACUPETO F2001	0.41	6.8	2324.6	244.7	46.3	18297.3	74.0
1088	PFAU/SERI,1B//AMAD /3/WAXWING/4/WBLL1*2	0.40	7.4	1986.1	283.7	44.6	18162.6	64.0
1251	MUNAL\WESTONIA	0.39	6.3	1519.5	189.9	37.8	15953.9	84.0
1082	KIRITATI/WBLL1// FRANCOLIN#1	0.38	6.2	1639.3	204.9	43.4	14471.3	70.6
1136	KLEIN DON ENRIQUE*2/3/FRET2/ WBLL1//…	0.37	5.9	1594.2	187.6	45.2	13319.9	71.0
1006	ATILLA*2/PBW65*2// KACHU	0.33	6.6	2047.7	215.5	37.4	18183.4	84.4
1164	WBLL1*2/BRAMBLING* 2//HEIL	0.34	7.3	2121.3	303.0	36.1	20356.3	67.2
Distorting average		0.37	6.61	1809.4	248.08	42.9	14608.6	67.6
Krasnodarskaya 99		0.43	6.35	1477.6	335.8	41.2	15422.3	45.9

HI - Harvest Index; TKW - 1000-kernel weight.

grains was significant. In analyzed samples, most samples with high grain yield also had high biomass. Noting that the grain yield was higher due to the yield index in one genotype, and the spikes per m^2, the grains per spike, and the grain weight per spike were more useful in production. The study discovered the spikes' average number in the accessions was 248.08. Above average occurred mainly in three genotypes, and the rest showed low values.

The wheat accessions also appeared to vary from each other for the 1000-kernel weight (TKW) indicator, ranging from 34.8 to 57.6 g, with the average value at 42.9 g. The above-average values for TKW were well-defined in the landraces, i.e., 1296 (46.4 g), 1131 (57.6 g), 1088 (44.6 g), 1082 (43.4 g), and 1136 (45.2 g), while low scores for the said trait came from the wheat genotypes 1289 (34.8 g) and 1251 (37.8 g). The lower average values of the wheat genotypes were mainly due to the rust-resistant samples K-1164 and K-1289, which have a TKW of 36.1 g and 34.8 g, respectively, and the grain yield was much lower than the average. Based on the results of studying the productivity parameters in wheat germplasm, a conclusion may be that the highest productivity usually depends first on the grains per unit area, followed by spikes per area, the grains per spike, and 1000-kernel weight.

DISCUSSION

Valuable wheat cultivars are a prime resource for enhancing wheat productivity significantly. In the wheat germplasm, eight genotypes selected as immune showed no symptoms of rust disease, and seven genotypes indicated a 10%–15% disease incidence; then, necrosis began to form around the symptoms, later stopping the infection from further developing. Similar results emanated in the experiments of 23 wheat genotypes found resistant to yellow rust, showing yellow rust affected the variations in their grain yield **(**Saeed *et al.,* 2015**).** Chlorophyll pigment is a low-level photoinhibitor under high-temperature stress, increasing heat tolerance (Asseng *et al.,* 2015).

By analyzing the chlorophyll content in wheat germplasm, the highest content of chlorophyll resulted in the wheat landraces K-1088 and K-1164 (2.54 ± 0.03 and 2.26 ± 0.37 mg/g, respectively) relative to the standard cultivar Krasnodarskaya-99 (2.10 ± 0.21 mg/g), and accessions K-1131 and K-1251 have shown the lowest content (1.36 ± 0.10 and 1.52 ± 0.10 mg/g, respectively). In past wheat experiments, they found that the wheat's late planting caused a significant decrease in resistance to yellow rust disease, leaf area, chlorophyll content, and productivity (Elbasyoni, 2018; Ahmad *et al*., 2023; Turaev *et al*., 2023).

In this study, the high chlorophyll pigment directly led to maximum rates of photosynthesis in timely planted genotypes. Strategies for increasing productivity through enhanced efficiency of photosynthesis are widely centers of discussion in global and local scientific research authenticated that grain yield can incur increases by improving the photosynthesis process (Roelfs *et al.,* 1992; Vicente-Serrano *et al.,* 2013; Ram *et al.,* 2017; Elbasyoni, 2018; Feng *et al.,* 2018). The research for improving the wheat genotypes with desirable traits' combination, including high photosynthetic efficiency under abiotic stress conditions, has extensively used marker-assisted selection (MAS), marker-assisted backcrossing (MARC), and gene pyramiding programs for genes involved in photosynthesis (Gupta *et al.,* 2017; Hussain *et al.,* 2018).

In the existing study, the value of economic signs was high, and productivity also increased. In previous research work, it revealed that the spike length has a direct positive impact on productivity (Pal *et al*., 2008, 2015; Yuan *et al.,* 2015). The number of spikelets on the spike also indicates the efficiency of the crop. In our studies, the number of spikelets per spike was as high as 19.5 units, which positively affected an increase in the grain yield. In past experiments on the number of spikelets per spike, they found that productivity sustained direct growth (Manuchehri and Salehi, 2014). A high number of grains per spike favorably caused a boost in the wheat grain yield (Roy *et al.,* 2021). Past studies also proved that the 1000-grain weight has directly benefitted wheat productivity (Zhang *et al.,* 2009). Findings also revealed that high chlorophyll content boosted the physiological processes and positively influenced the fertility of wheat and other crop plants (Gurvinder *et al.,* 2020; Hamlyn and Jones, 2007). Improving wheat productivity is essential to enhance the adaptability of the wheat genotypes to the soil and climatic conditions (Barrs and Weatherley, 1962). If the selection materializes in a stressful environment, it allows resistant and stable genotypes' segregation (Hatfield *et al.,* 2018; Bakhodirov *et al.,* 2021; Shavkiev *et al.,* 2023).

CONCLUSIONS

By comparing with the standard cultivar (Krasnodarskaya-99), the average values of the wheat accessions were low primarily due to the two rust-resistant genotypes, i.e., K-1164 and K-1289, where 1000-grain weight was 36.1 g and 34.8 g, respectively; however, the grain yield has the chief management of the grains per spike. The wheat genotypes, i.e., K-1088, K-1082, and K-1164, provided desirable values for chlorophyll a and b, total chlorophyll, carotenoid and relative water content, and leaf area, proving more productive and physiologically efficient under the environmental conditions of Tashkent, Uzbekistan. Quantitative productivity indicators of these wheat landraces incur positive differentiation because these genotypes emerged with higher values than the rest of the wheat accessions.

ACKNOWLEDGMENTS

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

Physiology, and the Durmon Experimental Field Station for providing the space and resources to carry out this work.

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