RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (1) 105-114, 2025
http://doi.org/10.54910/sabrao2025.57.1.11
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

PLANT LEAF CHLOROPHYLL RELATIONSHIP WITH YIELD ATTRIBUTES IN RICE

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SUMMARY

The timely research comprises analyses of chlorophyll content and morphological and yield-related traits and their mutual association in the 29 rice (*Oryza sativa* L.) genotypes (26 exotic and three local) under field conditions of Uzbekistan. Cluster analysis revealed the correlation of physiological, morphological, and yield-related traits in rice cultivars. Exotic genotypes, Aya, Goun, Haepyeong, IR-50404, Junomjosoeng, Polizesti-28, WAB 880 138 2017, Vietnam-1, Vietnam-2517, and Guru, recorded with low levels of association between chlorophyll content and morpho-yield traits. However, the chlorophyll content of four other exotic rice genotypes, DD2, Vikant, IR-86, and WAB WARDA, emerged with the highest relationship with morpho-yield traits. Foreign cultivars, Dongjin, Kuraj, Novator, Diamong, Osmancik-97, Sonet, and local Nukus-2, were notable with above-average values of chlorophyll content and morpho-yield traits. Cultivars DD2, Vikont, IR-86, and WAB WARDA owned the highest levels of chlorophyll a, b, total chlorophyll, and carotenoids. Exotic rice cultivars, Chongwang, CNC11, IR-124, WAB 450 113 462, Vietnam-2, Vietnam-3, and local Iskandar and Lazurniy, appeared with a good index for plant height, spike length, grains per spike, and grain weight per spike.

Keywords: Rice, *Oryza sativa* L., cultivars, morpho-yield, physiological traits, chlorophyll, carotenoids, correlation

Communicating Editor: Dr. Kamile Ulukapi
Manuscript received: March 17, 2024; Accepted: September 11, 2024.

Citation: Khamraev N, Nurmetova F, Ashirov M, Doschanov J, Shavkiev J, Jumaniyozova L, Rakhimov A, Yunusov O (2025). Plant leaf chlorophyll relationship with yield attributes in rice. *SABRAO J. Breed. Genet.* 57(1): 105-114. http://doi.org/10.54910/sabrao2025.57.1.11.

Key findings: Exotic rice (*O. sativa* L.) cultivars, Dongjin, Kuraj, Novator, Diamant, Osmancik-97, and Sonet, and local Nukus-2 emerged to be positive donors for initial selection for chlorophyll content and morpho-yield traits.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major cereal crop and the predominant staple feeding more than half of the world's population, approximately over 25% of the calorific needs (Kusano *et al.,* 2015). World rice production has witnessed a significant increase during the last half century due to an upsurge in harvest index by using semi-dwarf cultivars. These also required high inputs of fertilizers, pesticides indirectly causing environmental problems, outbreaks of diseases and pest-resistant insects, affecting human health as a primary concern (Birla *et al.,* 2017). However, since the mid-1980s, no significant increase was evident in rice yield.

The chief concerns are the rapidly increasing world population, ongoing severity of global climate change effects, water scarcity due to decreasing water table, reduction in rice cultivable land, and an increase in frequency and severity of extreme weather conditions (Stocker *et al.,* 2013). This potentially affected rice plant's growth and yield and the grains' physical and chemical properties (Birla *et al.,* 2017). Malnutrition has also become a primary concern in developing countries. Micronutrient malnutrition influences more than three billion people, killing 3.1 million people each year, with the death rate increasing with time (Gearing, 2015).

Modern agricultural farming necessitates accurate, quick, and non-destructive methods for the detection of plant physiological parameters (Alsina *et al.,* 2016). One of the commonly used parameters is the chlorophyll content in plant leaves. Chlorophyll concentration varies in plant leaves, depending on plant species background, environmental mineral elements, and various stress factors (Dong *et al.,* 2019). Measuring leaf chlorophyll concentration employed chlorophyll extraction in a solvent, followed by spectrometric measurement (Parry *et al.,* 2014).

Chlorophyll a (Chl a) and chlorophyll b (Chl b) are considerably the two most important leaf pigments, as accountable for most conversion of light energy into stored chemical energy within plants (Blackburn, 2007). Chl a is essential in the energy phase of photosynthesis, whereas Chl b captures the sunlight at a slightly different wavelength. Moreover, the pigment content variation in total chlorophyll among and within the species is crucial for several reasons, such as, photosynthetic activity and primary production (Flores-De-Santiago *et al.,* 2013).

Pigmentation is directly related to the plant's physiological stress conditions because chlorophyll concentration tends to decline with stress and aging of the plant. Consequently, quantifying these proportions can provide important information regarding the relationship between the crop plants and their surrounding environment (Flores-De-Santiago *et al.,* 2013; Baboeva *et al.,* 2023). However, a suggestion stated adopting chlorophyll content could be possible as a very useful in vivo indicator of heavy metal toxicity (Souahi, 2021). In light of the above discussion, the latest study aimed to quantify the morpho-yield and physiological traits in 29 cultivars and the correlation of leaf chlorophyll content with yield attributes in rice.

MATERIALS AND METHODS

Experimental site

The field experiment commenced in 2021 and 2022 at the Khorezm Grain and Legumes Plants Research Institute in the District Urgench, Khorezm Region, Uzbekistan (41°33'04.2" N 60°43'52.8" E). The Khorezm Region sits in the northern part of the Turan lowland, occupying part of the left bank of the ancient Amudarya Delta and a small part of the Kyzylkum Desert on the right bank. The Khorezm Region has a two-part division in terms of land structure, i.e., the large northern part at about 100–110 m above the sea level (masl) and the southern part at 120–150 masl. In this region, the average annual rainfall is 78–79 mm (most precipitation falls in spring and autumn), and the growing season lasts 200–210 days (Khamidov *et al.,* 2022).

Overall, the climate is sharply continental with frigid winters (up to -41 °C), hot (+25 °C to +30 °C), and sweltering summers (up to +45 °C). The average annual temperature of the oasis is +13.9 °C and +15 °C in the southern part of the oasis. Given its location in the desert zone, the climate is mostly dry. Agro-horticultural practices include the cultivation of cotton, rice, wheat, fruits, and vegetables, mainly irrigated. Saline groundwater is close to the soil surface and varies at a depth of 0.6–3.0 m. Special irrigation systems exist and a drainage system to drain the sewage. Such a farming system requires constant control of natural factors for obtaining the highest yields from the crops. Classical methods were operational for continuous monitoring (Ruzmetov *et al.,* 2020).

Plant material

The presented research used 29 rice cultivar samples collected from different countries, namely, South Korea (7), Vietnam (7), Russian Federation (4), WARDA (3), Philippines (2), Turkey (1), Ukraine (1), Romania (1), and Uzbekistan (3) (Table 1).

Table 1. Origin and country of rice genotypes.

No.	Rice genotypes	Country	Origin
1	Nukus-2	Uzbekistan	*O. sativa* L. ssp. japonica
2	Iskandar	Uzbekistan	*O. sativa* L. ssp. japonica
3	Lazurniy	Uzbekistan	*O. sativa* L. ssp. indica
4	Chongwang	South Korea	*O. sativa* L. ssp. indica
5	Dongjin	South Korea	*O. sativa* L. ssp. japonica
6	Haepyeong	South Korea	*O. sativa* L. ssp. japonica
7	Junomjosoeng	South Korea	*O. sativa* L. ssp. japonica
8	Aya	South Korea	*O. sativa* L. ssp. japonica
9	Goun	South Korea	*O. sativa* L. ssp. japonica
10	Guru	South Korea	*O. sativa* L. ssp. japonica
11	Osmancik-97	Turkey	*O. sativa* L. ssp. japonica
12	Polizesti-28	Romania	*O. sativa* L. ssp. japonica
13	Diamant	Russian Federation	*O. sativa* L. ssp. japonica
14	Kuraj	Russian Federation	*O. sativa* L. ssp. japonica
15	Novator	Russian Federation	*O. sativa* L. ssp. japonica
16	Sonet	Russian Federation	*O. sativa* L. ssp. japonica
17	Vikont	Ukraine	*O. sativa* L. ssp. japonica
18	Vietnam-1	Vietnam	*O. sativa* L. ssp. indica
19	Vietnam-2	Vietnam	*O. sativa* L. ssp. indica
20	Vietnam-2517	Vietnam	*O. sativa* L. ssp. indica
21	Vietnam-3	Vietnam	*O. sativa* L. ssp. indica
22	CNC11	Vietnam	*O. sativa* L. ssp. indica
23	DD2	Vietnam	*O. sativa* L. ssp. indica
24	IR-50404	Vietnam	*O. sativa* L. ssp. indica
25	IR-124	Philippines	*O. sativa* L. ssp. indica
26	IR-86	Philippines	*O. sativa* L. ssp. indica
27	WAB 450 113 462	WARDA*	*O. sativa* L. ssp. japonica
28	WAB 880 138 2017	WARDA*	*O. sativa* L. ssp. japonica
29	WAB WARDA	WARDA*	*O. sativa* L. ssp. japonica

*West Africa Rice Development Association

Analytical procedure

Accurately weighing 0.5 g of fresh plant leaf sample, we proceeded homogenizing in a tissue homogenizer with 10 ml of 95% ethanol. The homogenized sample mixture underwent centrifugation at 10,000 rpm for 15 min at +4 °C. Separating the supernatant continued with its 0.5 ml mixed with 4.5 ml of the 95% ethanol. The solution mixture sustained analysis for chlorophyll a, chlorophyll b, and carotenoid content through a spectrophotometer (Analytik jena Specord 50). Healthy and uninfected leaves' collection ensued at the flowering stage. Fresh leaf samples' thorough washing first used tap water, followed by distilled water in the laboratory, and then kept drying at room temperature (18 °C). Their analysis proceeded to determine various chlorophyll types (Ch-a 663 nm, Ch-b 645 nm, and carotenoids 470 nm) by following the methodology of Nayek *et al.* (2014).

Data recorded and statistical analysis

The data recording comprised various indicators of chlorophyll content and morphological and yield-related traits in rice cultivars. The correlation and cluster analyses of the various characters also transpired. These parameters served for comparison of the stress conditions with irrigated conditions. All the data underwent the analysis of variance (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

Mean performance

In crop plants, chlorophyll use in the process of photosynthesis helps absorb and convert light energy into chemical energy. Chlorophyll also has the name 'central pigment' of the photosynthetic reaction because it can accommodate light absorbed by other pigments through photosynthesis. Chlorophyll also plays a vital role in the process of plant organogenesis (Bahri, 2010).

By studying the physiological characteristics of the exotic and local cultivars, the lowest chlorophyll a was evident in the rice genotype Chongwang of the South Korean selection and Sonet variety of the Russian selection (5.52 ± 0.26 and 5.6 ± 0.26 mg/g, respectively). However, the highest values of the chlorophyll content were notable in the exotic genotypes DD2 and IR-86 of the Vietnam selection, WAB WARDA of the West Africa Rice Development Association (now Africa Rice Center) selection, and Vikont (17.97 ± 0.26, 24.35 ± 0.18, 17.2 ± 0.23, and 25.88 ± 0.33 mg/g, respectively). In exotic and local rice cultivars, the chlorophyll a content ranged from 8 to 13 mg/g (Table 2). The same indicators were also distinctive in the rice cultivars Kuraj, Nukus-2, IR-124, Osmancik-97, WAB 450 113 462, WAB 880 138 2017, Vietnam-1, Vietnam-2517, Vietnam-3, and Diamant.

According to some studies, the synthesis of chlorophyll depends on mineral nutrition (Bojovic and Stojanovi, 2005). Mineral nutrition significantly affects the dynamics of leaf surface formation and leaf surface area, as reflected in the total leaf surface amount, photosynthetic potential, and pure photosynthetic productivity. Of all the macro-metabolic elements, the one with the greatest influence on plant development in general and on the leaf surface is nitrogen, whose effects were enhanced by phosphorus and potassium.

In rice cultivars, the chlorophyll b ranged from 3.0 to 4.0 mg/g. The highest content of chlorophyll b was prominent in plant leaves of the exotic rice genotype WAB WARDA (5.63 ± 0.06 mg/g) and local cultivars Iskandar and Nukus-2 (4.69 ± 0.27 and 5.24 ± 0.05 mg/g). An observation revealed the amount of chlorophyll b was 1.7 ± 0.22 and 1.56 ± 0.09 mg/g in cultivars Polyzesti-28 and Vietnam-3, respectively. Earlier studies showed drought stress significantly reduced the leaf chlorophyll a and b contents in drought-sensitive and drought-tolerant rice genotypes (Pattanagul, 2011).

Table 2. Chlorophyll content in exotic and local cultivars of rice.

Cultivars	Chlorophyll a (mg/g)			Chlorophyll b (mg/g)			Carotenoid (mg/g)		
	Mean±SE	SD	Max-Min	Mean±SE	SD	Max-Min	Mean±SE	SD	Max-Min
Aya	6.5±0.3	0.61	7.3-5.83	3.21±0.44	0.88	4.25-2.09	1.78±0.34	0.69	2.68-1.01
Chongwang	5.52±0.26	0.51	6.2-4.97	2.58±0.19	0.38	3.00-2.08	1.8±0.19	0.38	2.29-1.37
CNC11	7.19±0.27	0.55	7.92-6.6	2.49±0.28	0.56	3.13-1.77	2.19±0.27	0.54	2.91-1.61
DD2	17.97±0.26	0.51	18.65-17.41	3.03±0.19	0.38	3.45-2.52	5.06±0.22	0.43	5.64-4.6
Dongjin	6.51±0.26	0.51	7.2-5.96	2.45±0.2	0.39	2.89-1.94	2.29±0.22	0.44	2.87-1.82
Goun	6.33±0.28	0.56	7.07-5.73	2.77±0.3	0.6	3.46-1.99	2.01±0.29	0.59	2.8-1.38
HAEPYEONG	6.52±0.24	0.48	7.16-6.01	2.41±0.1	0.2	2.61-2.13	2.18±0.07	0.14	2.31-1.99
IR-124	9.18±0.26	0.52	9.87-8.62	2.17±0.21	0.42	2.63-1.62	3.15±0.26	0.52	3.85-2.61
IR-50404	5.61±0.3	0.61	6.38-4.9	3.52±0.22	0.44	4.04-2.97	0.95±0.19	0.38	1.44-0.5
IR-86	24.35±0.18	0.36	24.85-23.99	3.59±0.23	0.46	4.1-2.99	6.91±0.03	0.06	6.96-6.83
JUNOMJOSOENG	7.68±0.19	0.38	8.2-7.35	2.3±0.19	0.39	2.65-1.76	2.72±0.2	0.41	3.28-2.31
Osmancik-97	8.98±0.2	0.39	9.51-8.58	3.54±0.14	0.28	3.83-3.16	2.49±0.02	0.03	2.52-2.44
Polizesti-28	7.46±0.27	0.53	8.08-6.78	1.7±0.22	0.45	2.12-1.08	2.82±0.08	0.16	2.99-2.6
WAB 450 113 462	8.19±0.28	0.57	8.94-7.57	3.26±0.34	0.67	4.04-2.4	2.63±0.31	0.63	3.47-1.96
WAB 880 138 2017	8.37±0.26	0.51	9.06-7.84	3.06±0.25	0.49	3.61-2.41	2.42±0.25	0.5	3.09-1.89
WAB WARDA	17.2±0.23	0.47	17.83-16.71	5.63±0.06	0.13	5.72-5.45	3.99±0.13	0.25	4.33-3.72
Vietnam -1	10.06±0.26	0.52	10.75-9.5	2.65±0.2	0.39	3.09-2.14	3.5±0.22	0.45	4.1-3.03
Vietnam -2	7.21±0.25	0.5	7.88-6.69	2.45±0.2	0.41	2.9-1.91	2.25±0.22	0.43	2.83-1.79
Vietnam -2517	12.66±0.41	0.81	13.6-11.62	3.06±0.34	0.69	3.93-2.25	3.33±0.36	0.73	4.29-2.54
Vietnam -3	11.21±0.21	0.41	11.77-10.78	1.56±0.09	0.18	1.73-1.31	4.08±0.08	0.16	4.31-3.95
Vikont	25.88±0.33	0.66	26.75-25.14	3.77±0.6	1.2	5.19-2.26	5.37±0.37	0.74	6.31-4.49
Guru	7.61±0.26	0.52	8.31-7.05	2.21±0.21	0.42	2.68-1.65	2.49±0.19	0.38	2.98-2.06
Diamant	12.65±0.28	0.56	13.39-12.04	3.02±0.32	0.64	3.75-2.2	3.57±0.26	0.51	4.24-2.99
Iskandar	5.26±0.26	0.53	5.86-4.58	4.69±0.27	0.54	5.41-4.11	0.77±0.27	0.54	1.49-0.2
Kuraj	8.74±0.24	0.47	9.37-8.24	2.51±0.08	0.15	2.64-2.29	3.19±0.09	0.17	3.4-2.98
Lazurniy	3.91±0.17	0.33	4.24-3.45	3.6±0.2	0.39	3.95-3.05	0.4±0.08	0.16	0.6-0.22
Novator	7.86±0.24	0.47	8.49-7.36	3.27±0.08	0.17	3.42-3.04	2.11±0.12	0.25	2.44-1.84
Nukus-2	10.51±0.23	0.46	11.13-10.03	5.24±0.05	0.09	5.32-5.11	2.54±0.1	0.21	2.82-2.32
Sonet	5.6±0.26	0.53	6.3-5.03	2.61±0.22	0.45	3.11-2.02	1.7±0.2	0.4	2.22-1.24

Quantitative variations in plant leaf pigments may occur in response to the disparity in environmental conditions (Esteban *et al.,* 2015). Environmental conditions considerably influence the leaf chlorophyll content compared with the qualitative composition of the pigments (Zunzunegui *et al.,* 2016). Knowingly, light is the main factor regulating the pigment content. Shading conditions increase the chlorophyll content per leaf mass and the share of chlorophyll b; however, decrease the share of carotenoids (Lambers and Chapin*,* 2008). Temperature and humidity variations in the environment can also affect the pigment composition of plant leaves (Esteban *et al.,* 2015).

Carotenoids are essential in photosynthesis and photoprotection (Hashimoto *et al*., 2016). They provide precursors for the biosynthesis of phytohormones abscisic acids (ABA) and strigolactones (SLs) (Al-Babili and Bouwmeester, 2015). Carotenoid derivatives also act as signaling molecules to mediate plant development and responses to environmental cues (Hou *et al*., 2016). Carotenoids are a large class of isoprenoid molecules synthesized by all photosynthetic and non-photosynthetic organisms (Andrew *et al*., 2008). In rice cultivar leaves, the carotenoid content ranged from 2.5 to 4.5 mg/g (Table 2). In plant leaves, the carotenoid content was maximum in the exotic cultivars DD2, IR-86, and Vikont (5.06 ± 0.22, 6.91 ± 0.03, and 5.37 ± 0.37 mg/g, respectively). The lowest values were apparently in the local rice cultivars Iskandar and Lazurniy (0.77 ± 0.27 and 0.4 ± 0.08 mg/g, respectively) and exotic genotype IR-50404 (0.95 ± 0.19 mg/g).

By studying the morphological and yield-related traits in rice genotypes, the taller plants recorded resulted from the exotic genotype IR-86 (102.63 ± 0.44 cm). Meanwhile, the lowest value recorded for the said trait appeared in the exotic rice genotypes, i.e., Aya, DD2, IR-50404, and Guru (46.73 ± 0.09, 47.27 ± 0.37, 47.3 ± 0.33, and 48.5 ± 0.37 cm, respectively). Among the rice genotypes, the local genotype Iskandar and exotic cultivars Chongwang, IR-124, WAB 450 113 462, and WAB WARDA were mostly found 80 to 90 cm tall.

Biometric traits manage the grain yield in all crops. This is because the yield determination has indicators, such as, the plant height, panicle length, grains per panicle, and 1000-grain weight (Tellyaev *et al*., 2021). The research conducted by these scientists in the Tashkent Region, Republic of Uzbekistan, studied biometric indicators of the rice cultivars Dongjin, Chongwang, Lazurniy, and Iskandar. As a result of the study, the cultivars emerged with varied values of plant height, i.e., Dongjin (96.7 cm), Chongwang (97.2 cm), Lazurniy (118 cm), and Iskandar (120 cm).

Panicle length and architecture are usually under yield-related traits' measurement. Panicle length, together with spikelet number and density, seed setting rate, and grain plumpness, determines the grain number per panicle managing the grain yield in rice (Erbao *et al*., 2016). Results revealed the highest panicle length was evident in exotic genotypes CNC11 and Vietnam-2 (21.57 ± 0.15 and 22.77 ± 0.27 cm, respectively), while the lowest values for said trait occurred in exotic cultivars Aya and Osmancik-97 (12.6 ± 0.25 and 12.99 ± 0.19 cm, respectively) (Table 3). According to the results, the spike length was mainly illustrating from 18 to 20 cm in the local cultivar Iskandar and exotic genotypes Chongwang, DD2 IR 124, IR 86, WAB WARDA, and Vietnam-3. Past studies also showed similar findings in studying the F1 hybrids of rice genotypes Chongwang, Dongjin, Osmancik-97, Polizesti-28, Iskandar, Lazurniy, Nukus-2, Novator, Sonet, Kuraj, and Diamant for plant height and 1000-grain weight (Khayitov *et al.,* 2021).

Table 3. Mopho-yield traits in exotic and local cultivars of rice.

Cultivars	Plant height (cm)			Grains panicle^{-1} (g)			Grain weight panicle^{-1} (g)		
	Mean±SE	SD	Max-Min	Mean±SE	SD	Max-Min	Mean±SE	SD	Max-Min
Aya	46.73±0.09	0.19	47-46.6	46.47±1.55	3.09	49.9-42.4	1.22±0.06	0.13	1.34-1.05
Chongwang	83.03±2.27	4.54	88.8-77.7	134.53±1.95	3.89	139.7-130.3	4.59±0.03	0.05	4.65-4.52
CNC11	58.83±0.49	0.97	60.2-58	114.57±4.73	9.46	124.4-101.8	2.39±0.1	0.2	2.53-2.11
DD2	47.27±0.37	0.74	48.2-46.4	129.97±3.68	7.35	139.5-121.6	1.99±0.08	0.16	2.21-1.84
Dongjin	62.73±2.04	4.08	67.8-57.8	136.9±1.01	2.02	138.8-134.1	4.61±0.03	0.06	4.7-4.56
Goun	59.8±0.29	0.57	60.5-59.1	98.83±2.33	4.66	103.8-92.6	2.42±0.05	0.11	2.57-2.32
HAEPYEONG	54.6±1.38	2.76	57.7-51	124.7±0.53	1.06	126.2-123.9	3.38±0.03	0.06	3.44-3.3
IR-124	88.7±1.39	2.78	91.7-85	149.07±2.1	4.2	155-145.9	3.49±0.06	0.12	3.66-3.38
IR-50404	47.3±0.33	0.65	48.1-46.5	106.63±1.98	3.95	110.1-101.1	2.56±0.04	0.08	2.62-2.44
IR-86	102.63±0.44	0.88	103.4-101.4	103.23±4.31	8.62	112.2-91.6	3.09±0.12	0.23	3.33-2.77
JUNOMJOSOENG	56.93±1	2.01	59.7-55	118±1.39	2.78	121.7-115	3.17±0.02	0.03	3.19-3.12
Osmancik-97	66.6±0.72	1.44	68.2-64.7	163.77±2.41	4.82	170.2-158.6	4.48±0.01	0.02	4.51-4.46
Polizesti-28	58.6±0.59	1.18	60.2-57.4	103.1±1.02	2.05	105.7-100.7	3.08±0.03	0.06	3.17-3.03
WAB 450 113 462	85.58±0.88	1.76	87.9-83.65	129.07±6.73	13.46	146.1-113.2	3.84±0.24	0.48	4.49-3.36
WAB 880 138 2017	67.7±0.54	1.07	68.9-66.3	81.83±1.63	3.26	84.8-77.3	2.97±0.06	0.13	3.06-2.79
WAB WARDA	87.93±0.81	1.62	90.1-86.2	126.87±2.8	5.6	134.7-121.9	3.85±0.1	0.2	4.12-3.64
Vietnam -1	52.8±0.07	0.14	52.9-52.6	105.53±2.19	4.38	111.7-101.9	2.72±0.06	0.12	2.89-2.61
Vietnam -2	58.43±0.69	1.39	59.7-56.5	158.93±6.64	13.28	176.5-144.4	2.89±0.14	0.29	3.29-2.67
Vietnam -2517	53.87±0.8	1.6	55.5-51.7	105.5±1.65	3.31	109.6-101.5	2.46±0.04	0.08	2.56-2.37
Vietnam -3	61.37±0.75	1.51	63.4-59.8	153±5.97	11.95	165.9-137.1	3.3±0.18	0.36	3.57-2.79
Vikont	58.77±0.47	0.94	59.9-57.6	98.2±3.73	7.46	106.8-88.6	1.78±0.06	0.13	1.92-1.61
Guru	48.5±0.37	0.73	49.4-47.6	91.6±1.71	3.42	96.1-87.8	2.2±0.04	0.07	2.28-2.1
Diamant	63.68±0.77	1.53	65.55-61.8	139.2±5.33	10.66	148.6-124.3	3.54±0.1	0.2	3.75-3.28
Iskandar	86.83±0.65	1.3	87.8-85	151.93±0.67	1.35	153.3-150.1	4.51±0.1	0.21	4.8-4.36
Kuraj	69.03±0.59	1.18	70.5-67.6	137.4±8.34	16.68	160.8-123.1	4.08±0.18	0.36	4.51-3.64
Lazurniy	75.37±1.05	2.1	78.3-73.5	110.73±0.91	1.81	113.1-108.7	3.28±0.03	0.06	3.34-3.2
Novator	59.03±0.29	0.57	59.7-58.3	133.33±4.38	8.76	145.7-126.5	3.66±0.08	0.16	3.87-3.5
Nukus-2	57.72±0.27	0.54	58.3-57	138.27±2.92	5.83	143.8-130.2	3.62±0.01	0.03	3.65-3.59
Sonet	55.87±0.69	1.38	57.8-54.7	161.73±2.46	4.91	168.4-156.7	4.09±0.05	0.1	4.2-3.96

For grains per ear, the highest values resulted in the exotic genotypes Osmancik-97, Vietnam-2, Vietnam-3, and Sonet (163.77 ± 2.41, 158.93 ± 6.64, 153 ± 5.97, and 161.73 ± 2.46 grains) and the local cultivar Iskandar (151.93 ± 0.67 grains) (Table 3). The lowest number of grains per ear came from the rice genotype Aya (46.47 ± 1.55 grains). The results further revealed the rice cultivars Navotar, Nukus-2, Kuraj, Chongwang, DD2, Dongjin, Haepyeong, IR-124, WAB 450 113 462, WAB WARDA, and Diamant were mostly with 125 to 140 grains per panicle. Morales (1986) suggested grains per panicle and 1000-grain weight seemed as important criteria for enhancing grain yield/unit area. Moeljopawiro (1989) reported grains/panicle was the yield-determining component with the greatest effect. On the contrary, Ibrahim *et al*. (1990) reported productive tillers were the most reliable character in selecting rice genotypes. Mehetre *et al*. (1994) stated the filled grains/panicle was a crucial yield-contributing character.

By studying the grain weight per panicle in rice cultivars, the obtained highest values were from exotic cultivars Chongwang, Dongjin, Osmancik-97, Iskandar, Kuraj, and Sonet (4.59 ± 0.03, 4.61 ± 0.03, 4.48 ± 0.01, 4.51 ± 0.1, 4.08 ± 0.18, and 4.09 ± 0.05 g, respectively). However, the lowest grain weight per panicle surfaced from exotic cultivars Aya, CNC11, and Vikont (1.22 ± 0.06, 1.99 ± 0.08, and 1.78 ± 0.06 g, respectively). The experiment also determined the grain weight per ear, ranging from 3 to 4 g in several rice genotypes (Table 3).

The correlation between leaf area and grain yield suggested chlorophyll and leaf area proved more important in determining the yield (Raj and Tripathi, 1999). The chlorophyll content in leaf tissues varies with the age of the plant, the crop species, and the growing season (Yurkovskii *et al.,* 1977). The chlorophyll role in photosynthesis is well established; however, the relationship between the chlorophyll content and the rate of photosynthesis is equivocal (Ashraf and Khan, 1993; Rauf *et al*., 2024).

According to general analysis of the physiological and morpho-yield characteristics of rice genotypes in the Khorezm Region of the Republic of Uzbekistan, the physiological traits recorded as chlorophyll a (9.7 mg/g), chlorophyll b (3.04 mg/g), the total chlorophyll (12.9 mg/g), and carotenoid content (2.8 mg/g). According to morpho-yield traits, the values comprised average plant height (64.7 cm), spike length (17.2 cm), grains per spike (122.5), and spike weight (3.2 g) (Table 4).

Correlation coefficient

The correlation between the physiological and morpho-yield characteristics of the rice cultivars underwent scrutiny. A considerable positive correlation existed between the chlorophyll a and the total chlorophyll and carotenoid content (r = 0.988*** and r = 0.920***, respectively). Chlorophyll b revealed a reliable average positive correlation with total chlorophyll (r = 0.451*) and plant height (r = 0.321*) (Table 5). A reliable, strong positive correlation (r = 0.866***) emerged between the total chlorophyll content and the carotenoid content. The carotenoid content and the grain weight per ear indicated a weak reliable negative correlation (r = -0.240**), while a significant positive correlation (r = 0.734***) with the number of grains per spike.

Cluster analysis

The agglomeration schedule showed all the observations aggregated at each stage of the clustering process. At the first stage, observation 7 gathered with observation 11. The distance between the combined groups was 0.330672. It also showed the next stage at which this combined group further grouped with another cluster, as stage 4. According to the cluster analysis of the correlation of physiological and morphological and yield-related traits of rice cultivars, four groups were distinct (Figure 1). Ten genotypes belonged in groups 1 and 8 genotypes in groups 2 and 4 genotypes in groups 3 and 7 samples of exotic and local rice cultivars in group 4.

In group 1, the genotypes were Aya, Goun, Haepyeong, IR-50404, Junomjosoeng, Polizesti-28, WAB 880 138 2017, Vietnam-1, Vietnam-2517 and Guru, which owned low

Table 4. Statistical analysis of various physiological and morpho-yield traits.

Traits	Mean	Stand. error	Lower limit	Upper limit	Sigma
Chlorophyll a	9.74897	0.994296	7.71224	11.7857	5.35445
Chlorophyll b	3.04655	0.173019	2.69214	3.40097	0.931735
Total chlorophyll	12.7945	1.06005	10.6231	14.9659	5.70854
Carotenoid	2.78241	0.254761	2.26056	3.30427	1.37193
Plant height	64.6976	2.69999	59.1669	70.2283	14.5399
Panicle length	17.2359	0.442648	16.3291	18.1426	2.38373
Grains per panicle	122.513	4.93204	112.411	132.616	26.5599
Grain weight per panicle	3.21586	0.162083	2.88385	3.54787	0.872842

Table 5. Correlation of chlorophyll content, and morphological and yield-related traits in exotic and local cultivars of rice.

Traits	Chlorophyll b	Total chlorophyll	Carotenoids	Plant height	Panicle length	Grains per panicle	Grain weight panicle^{-1}
Chlorophyll a	0.307	0.988***	0.920***	0.217	0.109	-0.114	-0.291
Chlorophyll b		0.451*	0.017	0.321*	-0.088	0.006	0.138
Total chlorophyll			0.866***	0.256	0.088	-0.106	-0.250
Carotenoids				0.207	0.121	-0.058	-0.240**
Plant height					0.277	0.264	0.538
Panicle length						0.251	-0.052
Grains per panicle							0.734***

Note: Significant at $P \leq 0.05$*, $P \leq 0.01$**, and $P \leq 0.001$***

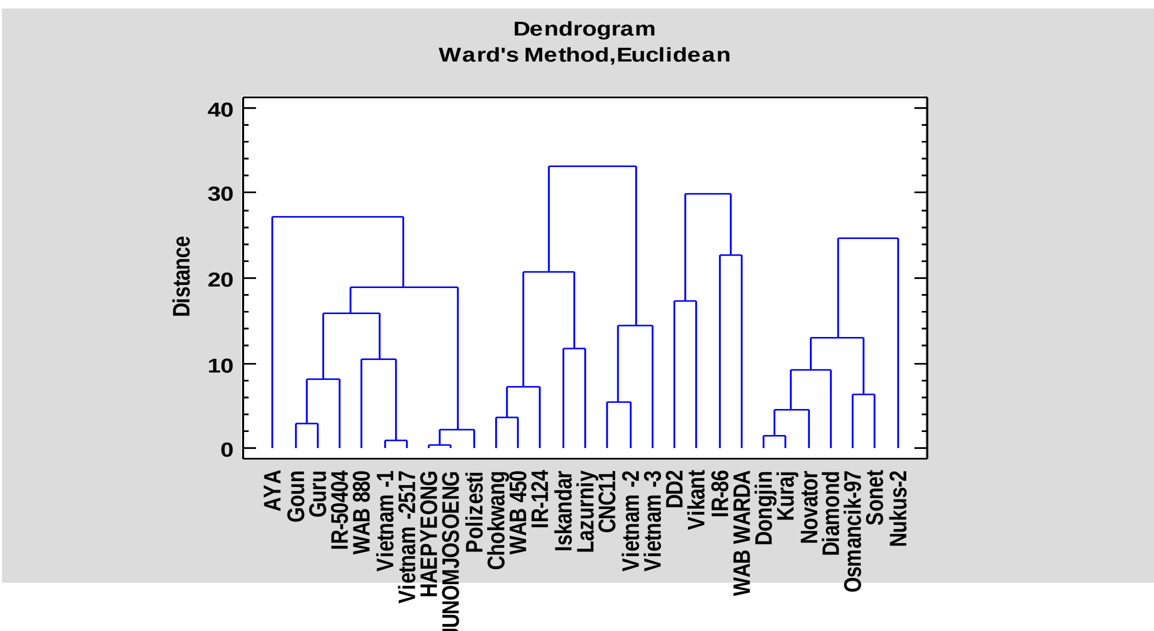

Figure 1. Dendrogram of the analysis of chlorophyll content, and morphological and yield-related traits in exotic and local cultivars of rice.

physiological and morpho-yield traits. Group 2 includes the rice cultivars Chongwang, CNC11, IR-124, WAB 450 113 462, Vietnam-2, Vietnam-3, and local genotypes Iskandar and Lazurniy, which are at an average level, according to the morpho-yield traits. Physiological traits of the rice genotypes DD2, Vikont, IR-86, and WAB WARDA were notable at high levels in three groups. Cultivars Dongjin, Kuraj, Novator, Diamant, Osmancik-97, Sonet, and Nukus-2 appeared in four groups. The study further revealed that these rice genotypes were above the average level in morpho-yield and physiological traits.

CONCLUSIONS

Based on the results, exotic rice cultivars DD2, Vikont, IR-86, and WAB WARDA have the maximum levels of chlorophyll a, b, total chlorophyll, and carotenoids. Exotic genotypes Chongwang, CNC11, IR-124, WAB 450 113 462, Vietnam-2, Vietnam-3, and local cultivars Iskandar and Lazurniy revealed to have a good index for plant height, spike length, grains per spike, and grain weight per spike. Exotic rice cultivars Dongjin, Kuraj, Novator, Diamant, Osmancik-97, Sonet, and local cultivar Nukus-2 proved to be positive donors of physiological and morpho-yield traits.

ACKNOWLEDGMENTS

The authors thank the Khorezm Scientific Experimental Station of the Grain and Legumes Plants Research Institute, for providing space and resources to carry out this work. We express our gratitude to the Rice Research Institute of Uzbekistan for practical assistance in using the collection of rice cultivars.

REFERENCES

Al-Babili S, Bouwmeester HJ (2015). Strigolactones, a novel carotenoid-derived plant hormone. *Ann. Rev. Plant Biol.* 66: 161–186.

Alsina I, Duma M, Dubova L, Senberga A, Dagis S (2016). Comparative methods for chlorophyll detection in leaves. *Agron. Res.* 14(2): 309.

Andrew JS, Moreau H, Kuntz M, Pagny G, Lin C, Tanksley S, McCarthy J (2008). An investigation of carotenoid biosynthesis in *Coffea canephora* and *Coffea arabica*. *J. Plant Physiol.* 165: 1087–1106.

Ashraf MY, Khan AH (1993). Characterization of induced high temperature chlorophyll mutant in rice. *Sci. Int.* 6: 73–75.

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.

Bahri S (2010). Klorofil. Diktat kuliah kapita selekta kimia organik. Universitas *Lampung.* 2: 49–56.

Birla DS, Malik K, Sainger M, Chaudhary D, Jaiwal R, Jaiwal PK (2017). Progress and challenges in improving the nutritional quality of rice (*Oryza sativa* L.). *Crit. Rev. Food Sci. Nutr*. 57(11): 2455–2481. https://doi.org/10.1080/10408398.2015.1084992

Blackburn GA (2007). Hyperspectral remote sensing of plant pigments. *J. Exp. Bot.* 58: 855–867, https://doi.org/10.1093/jxb/erl123.

Bojovic BM, Stojanovi J (2005). Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. *Arch. Biol. Sci.* 57(4): 283–290. https://doi.org/10.2298/ABS0504283B.

Dong T, Shang J, Chen JM, Liu J, Qian B, Ma B, Morrison MJ, Zhang C, Liu Y, Shi Y, Pan H, Zhou G (2019). Assessment of portable chlorophyll meters for measuring crop leaf chlorophyll concentration. *Remote Sens.* 11, 2019, https://doi:10.3390/rs11222706.

Erbao L, Yang L, Guocan W, Siyuan Z, Thu GT, Lijun L, Yinfeng L, Zhiyao D, Dong S, Hui W, Imdad UZ, Delin H (2016). Identification of a candidate gene for panicle length in rice (*Oryza sativa* L.) via association and linkage analysis. *Front Plant Sci*. 7: 596. doi:10.3389/fpls.2016.00596.

Esteban R, Barrutia O, Artetxe U, Fernandez-Marin B, Hernandez A, Garcia-Plazaola JI (2015). Internal and external factors affecting photosynthetic pigment composition in plants: A meta-analytical approach. *New Phytol.* 206: 268. https://doi.org/10.1111/nph.13186.

Flores-De-Santiago F, Kovacs JM, Flores-Verdugo F (2013). Assessing the utility of a portable pocket instrument for estimating seasonal mangrove leaf chlorophyll contents. *Bull. Mar. Sci.* 89(2): 621, https://doi.org/10.5343/bms.2012.1032.

Gearing ME (2015) Good as gold: Can golden rice and other biofortified crops prevent malnutrition? *Science in the News.* Harvard University, Cambridge, MA. http://sitn.hms.harvard.edu/

Hashimoto H, Uragami C, Cogdell RJ (2016). Carotenoids and photosynthesis. *Subcell. Biochem.* 79: 111–139.

Hou X, Rivers J, Leo'n P, McQuinn RP, Pogson BJ (2016). Synthesis and function of apocarotenoid signals in plants. *Trend. Plant Sci.* 21: 792–803.

Ibrahim S, Ramalingam A, Subramaniam M (1990). Path analysis of rice grain yield under rainfed lowland conditions. *J. IRRN* 15(1): 11.

Khamidov M, Ishchanov J, Hamidov A, Donmez C, Djumaboev K (2022). Assessment of soil salinity changes under the climate change in the Khorezm region, Uzbekistan. *Int. J. Environ. Res. Public Health* 19: 8794. https://doi.org/10.3390/ijerph19148794.

Khayitov MY, Qalandarov BI, Ergashev MA, Axtamov MA (2021). Study of rice genotypes and their use in the process of selection. *E3S Web of Conf. 244* 02001 https://doi.org/10.1051/e3sconf/202124402001 EMMFT-2020.

Kusano M, Yang Z, Okazaki Y, NakabAyashi R, Fukushima A, Saito K (2015). Using metabolomic approaches to explore chemical diversity in rice. *Mol. Plant* 8: 58–67.

Lambers H, Chapin FS, Pons TL (2008). Plant Physiological Ecology. Springer, New York.

Mehetre SS, Mahajan CR, Pati PA, Lad SK, Dhumal PM (1994). Variability, heritability, correlation, path analysis, and genetic divergence study in upland rice. *J. IRRN* 19(1): 8–10.

Moeljopawiro S (1989). Genotype-environment interaction of nine rice promising lines. *Indonesian J. Crop Sci*. 4(1): 1–8.

Morales A (1986). Analysis of yield and yield components of rice (*Oryza sativa* L.) cultivars and lines. *Cultivas Tropicales* 8(3): 79–85.

Nayek S, Choudhury I, Haque JN, Roy S (2014). Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. *Res. J. Chem. Sci.* 4(9): 63–69.

Parry C, Blonquist JM, Bugbee B (2014). In situ measurement of leaf chlorophyll concentration: analysis of the optical/absolute relationship. *Plant Cell Environ.* 37: 2508, https://doi.org/10.1111/pce.12324.

Pattanagul W (2011). Exogenous abscisic acid enhances sugar accumulation in rice (*Oriza sativa* L.) under drought stress. *Asian J. Plant Sci*. 10: 212–219.

Raj A, Tripathi MP (1999). Relationship of leaf area and chlorophyll content with yield in deep water rice. *Indian J. Plant Physiol.* 4: 219–220.

Rauf A, Barus WA, Munar A, Lestami A (2024). Physiological characteristics of the red rice with application of ascorbic acid under salinity stress conditions. *SABRAO J. Breed. Genet.* 56(4): 1437-1445. http://doi.org/10.54910/sabrao2024.56.4.10.

Ruzmetov R, Matyakubova Y, Abdullaev I (2020). Cytosporosis diseases of apple trees (Reinette Simirenkomalus) and its distribution in the lower Amudarya region. *Int. J. Curr. Res. Rev.* 12(14): 62–67. doi: 10.31782/IJCRR.2020.121413.

Souahi H (2021). Impact of lead on the amount of chlorophyll and carotenoids in the leaves of *Triticum durum* and *T. aestivum, Hordeum vulgare,* and *Avena sativa*. *Biosyst. Divers.* 29(3): https://doi.org/10.15421/012125.

Steel RGD, Torrie JH, Dicky DA (1997). Principles and Procedures of Statistics, A Biometrical Approach. McGraw Hill, Inc. Book Co., 3rd Edition, New York, pp. 352–358.

Stocker BD, Roth R, Joos F, Spahni R, Steinacher M, Zaehle S, Bouwman L, Ri X, Prentice IC (2013). Multiple greenhouse gas feedbacks from the land biosphere under future climate change scenarios. *Nat. Clim. Change* 3: 666-672.

Tellyaev R, Ergashev M, Kodirov B, Kholboev A (2021). Influence of sowing methods on biometric indicators of local and international rice varieties. *E3S Web of Conf.* 244, 02029 https://doi.org/10.1051/e3sconf/ 202124402029 EMMFT-2020.

Yurkovskii AH, Bramane AE, Yurkovska VA (1977). A cycle of variations of phyto-plankton pigments and bacterioplankton in the Baltic Sea. *Okenologiya* 16: 830–838.

Zunzunegui M, Diaz-Barradas MC, Jauregui J, Rodriguez H, Alvarez-Cansino L (2016). Season-dependent and independent responses of Mediterranean scrub to light conditions. *Plant Physiol. Biochem.* 102: 80-91. https://doi.org/10.1016/j.plaphy.2016.02.004.