RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (6) 2434-2444, 2025
http://doi.org/10.54910/sabrao2025.57.6.17
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

BREEDING RICE FOR WATER-STRESS TOLERANCE: YIELD OPTIMIZATION AND STRESS TOLERANCE INDICES

A. NASIM[1*], S.M.A. SHAH[1], S.A. JADOON[1], S.U. KHAN[2], M. AHMAD[1], and M. AQIB[1]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Peshawar, Pakistan
[2]Institute of Biotechnology and Genetic Engineering, University of Agriculture, Peshawar, Pakistan
*Corresponding author's email: afraznasim99@gmail.com
Email addresses of co-authors: mehrpbg@aup.edu.pk, sultan@aup.edu.pk, shahidkhanbiotech@gmail.com, muzammilahmadaup@gmail.com, aqibaryaan222@gmail.com

SUMMARY

Development of water-stress-tolerant rice (*Oryza sativa* L.) cultivars is imperative to ensure food security. With this background, 36 rice genotypes comprising six parental genotypes and 30 advanced rice populations underwent water-stress tolerance evaluation using water-stress and irrigated field conditions. Significant ($p \leq 0.05$) differences were evident among the genotypes, environments, and genotype-by-environment interactions for yield-related traits. Yield depreciation of rice genotypes under water-stress conditions varied depending on their genotypic tolerance potential. Stress tolerance indicators, such as stress susceptibility index (SSI), stress tolerance index (STI), and yield index (YI), along with the principal component analysis (PCA), served to identify water-stress-tolerant genotypes. For water-stress conditions, the highest grain yield per plant (GY) and desirable stress tolerance indices resulted in G09 (GY = 25.56 g; SSI = −0.36; STI = 1.23; YI = 1.45), G31 (GY = 21.16 g; SSI = −1.50; STI = 0.69; YI = 1.20), G32 (GY = 22.36 g; SSI = −0.59; STI = 0.90; YI = 1.27), and G34 (GY = 21.88 g; SSI = −1.40; STI = 0.75; YI = 1.24). These promising genotypes can be favorable for the development of water-stress-tolerant cultivars through future breeding programs.

Keywords: Rice (*O. sativa* L.), advanced rice populations, genotype-by-environment interactions, water-stress tolerance, water-stress-tolerance indices, grain yield

Key findings: Newly developed rice (*O. sativa* L.) genotypes G09, G31, G32, and G34 displayed water-stress-tolerance profiles with the highest grain yield and desirable stress tolerance indices.

Communicating Editor: Prof. Dr. Ijaz Rasool Noorka

Manuscript received: May 24, 2025; Accepted: September 06, 2025.
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Citation: Nasim A, Shah SMA, Jadoon SA, Khan SU, Ahmad M, Aqib M (2025). Breeding rice for water-stress tolerance: Yield optimization and stress tolerance indices. *SABRAO J. Breed. Genet.* 57(6): 2434-2444. http://doi.org/10.54910/sabrao2025.57.6.17.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major cereal crop of the Poaceae family and a member of the genus *Oryza*. It serves as a staple food for over half of the global population (Kaur *et al.,* 2024; Sikirou *et al.,* 2024). The population of the world is rapidly increasing, with an expectation to reach 10 billion by 2050. According to the International Rice Research Institute (IRRI) estimates, global rice production needs boosting by an additional 75 million tons from the 2020 baseline milled rice production of 518.2 million tons (Lianos, 2025; Pede *et al*., 2023). This situation demands a substantial enhancement in rice production at times, with stagnant yield in most rice-growing countries facing the challenges of climate change and biotic and abiotic stresses in rice production systems (Mata *et al.,* 2023).

Enhancing rice productivity through improved yield components and resistance to biotic and abiotic stresses is essential to ensure food security for the growing global population (Iqbal *et al.,* 2023). Among other stresses, water stress is a major global constraint for rice production systems (Khanthavong *et al.,* 2021; Chen *et al.,* 2024). Water stress at the vegetative and reproductive phases of rice crop causes a significant decline in the performance of key yield traits (Wang *et al.,* 2025), accounting for almost 50% of rice yield losses at the harvest stage worldwide (Zhang *et al.,* 2018; Aklilu *et al.,* 2024). This situation will worsen with ongoing climate change in rice-growing regions (Itoh *et al.,* 2024).

In Pakistan, the rice crop also experiences water stress at critical growth stages due to irrigation shortages and low rainfall. Reduced water supply at critical crop growth stages (Adjah *et al.,* 2025; Islam *et al*., 2025) leads to substantial yield reduction (Wei *et al.,* 2022; Fauziah *et al.*, 2024). Identification and development of new water-stress-tolerant rice cultivars is, therefore, imperative for ensuring global food security (Sahebi *et al.,* 2018).

The water-stress-tolerance potential of rice genotypes can be assessed using several stress tolerance indicators. These indices assemble yield performance under both stress and non-stress environments and thus, provide a reliable basis for desirable genotype(s) selection. In addition, combining multiple indices optimizes the accuracy of recognizing stable, high-yielding cultivars for drought-prone environments (Kandel *et al.,* 2022). Therefore, the following study took place to assess the water-stress-tolerance potential of newly developed rice populations and identify high-yielding, water-stress-tolerant genotypes for the development of new water-stress-tolerant rice cultivars, along with their potential use in rice hybridization programs.

MATERIALS AND METHODS

Genetic material and procedure

This study began during the rice-growing season of 2022 at the University of Agriculture (UoA), Peshawar, Pakistan. The experimental material comprised six parents (AUP-1 to AUP-6) and 30 newly developed advanced rice populations (AUP-7 to AUP-36) for water-stress tolerance (presented in different tables). These populations resulted from crosses among elite rice cultivars, as provided by the Rice Breeding Program, Department of Plant Breeding and Genetics, UOA-Peshawar. The genotypes, planted in a randomized complete block design, had three replications under normal and water-stress conditions. Data recording was on a plot basis for days to heading, with data for yield traits collected from 10 randomly selected plants in each replication centered on flag leaf area, plant height, grains per panicle, 1000-seed weight, and grain yield per plant.

Statistical analyses

Data compilation and analysis used pooled analysis of variance as described by Gomez and Gomez (1984). Different stress tolerance indices' calculations were as follows: stress susceptibility index (Fischer and Maurer, 1978); stress tolerance index, geometric mean productivity, and harmonic mean (Fernandez, 1992); mean productivity index and drought resistance index (Rosielle and Hamblin, 1981);

Table 1. The analysis of variance of 36 rice genotypes for days to heading (DH), flag leaf area (FLA), plant height (PH), grains per panicle (GPP), 1000-seed weight (SW), and grain yield per plant (GY).

Traits	Environments df = 1	Reps w/n Environ. df = 4	Genotypes df = 35	G × E df = 35	Error df = 140
DH	465.23*	52.69	52.72**	32.88**	15.05
FLA	2877.37*	331.13	119.44**	118.80**	6.79
PH	4756.41*	588.81	343.92**	116.58**	33.70
GPP	1405.00*	141.69	3000.21**	3658.22**	72.80
SW	1023.77*	126.50	64.88**	47.44**	2.08
GY	1119.68*	72.66	19.82**	22.04**	7.11

** Significant at a 1% probability level; * Significant at a 5% probability level.

yield index (Gavuzzi *et al.,* 1997); and yield stability index (Bouslama and Schapaugh, 1984). The study performed the principal component analysis using the mean grain yield of genotypes under normal and water-stress conditions, along with their stress tolerance indices, in R-Studio (R Core Team, 2024).

RESULTS AND DISCUSSION

Pooled analysis of variance revealed significant differences among the environments for all studied traits at the 5% probability level. Mean squares for genotypes and genotype-by-environment interactions emerged as significant ($p \leq 0.01$) for the studied maturity and yield traits (Table 1). These results were consistent with those of Perween *et al.* (2020), who studied 48 rice genotypes for yield and related traits under normal and water-stress conditions and reported significant differences among the genotypes under both conditions for yield traits. Abbas *et al.* (2024) also noted similar results in their study comprising 35 rice genotypes tested under irrigated and water-stress conditions.

Mean performance of rice genotypes

The rice genotypes showed substantial variation in the mean values for the studied traits under both normal and water-stress conditions. Under normal conditions, the mean values of rice genotypes ranged from 92.5 to 108.0 days for days to heading, 15.7 to 43.4 cm^2 for flag leaf area, and 83.1 to 124.7 cm for plant height. Other mean values were 60.7 to 198.1 for grains per panicle, 17.8 to 41.0 g for 1000-seed weight, and 16.2 to 27.3 g for grain yield per plant. Genotypes G10, G29, and G01 exhibited the highest values for grains per panicle, 1000-seed weight, and grain yield per plant, respectively (Table 2, Table 3). Chattar *et al.* (2025) evaluated 40 rice genotypes for yield traits and documented noteworthy differences among genotypes. Their recorded mean ranges for days to heading (87–106 days) and grain yield per plant (18.7–27.25 g) were consistent with the present findings. Similarly, Pavithra *et al.* (2022) assessed 48 genotypes under both irrigated and water-stress conditions and noted remarkable variation in yield components, including plant height (70.9–117.7 cm) under irrigated conditions. Bhusal *et al.* (2023) evaluated 52 genotypes and reported a comparable range for flag leaf area (14.4–45.9 cm^2) under irrigated conditions.

For water-stress conditions, the mean values of rice genotypes for studied traits varied from 88.7 to 104.0 days for days to heading, 14.4 to 32.7 cm^2 for flag leaf area, and 71.7 to 109.0 cm for plant height. Other values were 66.8 to 207.5 for grains per panicle, 15.7 to 27.0 g for 1000-seed weight, and 12.6 to 25.6 g for grain yield per plant. Genotypes G31, G26, and G09 displayed the highest values for grains per panicle, 1000-seed weight, and grain yield per plant, respectively (Tables 2 and 3). Swathi *et al.* (2023) evaluated 50 rice genotypes under water-stress conditions and observed significant differences for yield traits. They reported mean ranges for days to heading (58–114 days), plant height (72–134 cm), and grain yield per plant (8–27 g), which aligned with the presented findings. Similarly, the mean values for flag leaf area, as recorded in this study, were compatible with the findings of El-Hashash *et al.* (2018), who evaluated 17 rice genotypes under both irrigated and water-stress conditions.

Water-stress impact on maturity and yield traits

As illustrated in Figure 1A, water stress accelerated flowering for most studied genotypes. This phenological response suggested a water-stress escape strategy, where plants shortened their growth duration to complete their life cycle before severe water

Table 2. Mean performance and trait percent reduction of 36 rice genotypes for days to heading, flag leaf area, and plant height under normal conditions (NC) and water-stress conditions (WSC).

Genotypes	Days to heading			Flag leaf area (cm^2)			Plant height (cm)		
	NC	WSC	Reduction (%)	NC	WSC	Reduction (%)	NC	WSC	Reduction (%)
G01	102	97	-5	33	21	-36	89	75	-15
G02	102	100	-1	43	19	-55	116	85	-27
G03	100	103	3	25	16	-38	90	82	-9
G04	102	103	1	33	30	-8	125	109	-13
G05	107	104	-3	34	33	-4	109	72	-34
G06	101	96	-4	32	25	-21	83	81	-2
G07	106	101	-5	43	19	-55	104	80	-23
G08	103	101	-1	32	20	-38	91	87	-5
G09	99	99	1	25	22	-9	108	106	-2
G10	101	94	-7	19	19	-3	102	98	-4
G11	108	99	-8	28	26	-6	88	97	11
G12	94	91	-2	24	22	-11	110	96	-13
G13	100	101	1	23	17	-26	88	89	1
G14	97	90	-7	24	19	-19	94	80	-15
G15	100	93	-7	19	28	48	91	81	-12
G16	101	101	0	29	19	-36	97	94	-3
G17	93	93	1	33	15	-56	91	87	-4
G18	93	100	8	16	15	-5	98	87	-11
G19	101	98	-3	38	18	-54	108	94	-13
G20	97	100	3	32	16	-50	108	93	-14
G21	100	97	-3	19	24	31	95	86	-9
G22	102	89	-13	26	30	12	109	100	-8
G23	103	91	-12	24	18	-24	93	90	-3
G24	104	96	-8	41	22	-48	97	89	-9
G25	96	98	2	29	16	-46	94	82	-13
G26	101	103	2	19	15	-20	93	80	-14
G27	102	99	-3	25	22	-13	91	72	-21
G28	98	100	3	32	29	-11	98	92	-6
G29	101	96	-4	19	16	-16	97	92	-6
G30	102	98	-4	32	17	-46	93	89	-5
G31	100	101	1	18	24	32	100	92	-8
G32	107	96	-10	21	21	-1	99	98	-1
G33	103	98	-5	28	18	-37	86	83	-4
G34	102	100	-2	36	14	-59	98	88	-11
G35	102	101	-1	20	26	29	90	85	-6
G36	101	91	-10	33	16	-51	92	90	-3

Table 3. Mean performance and trait percent reduction of 36 rice genotypes for grains per panicle, 1000-seed weight, and grain yield per plant under normal conditions (NC) and water-stress conditions (WSC).

Genotypes	Grains per panicle			1000-seed weight (g)			Grain yield per plant (g)		
	NC	WSC	Reduction (%)	NC	WSC	Reduction (%)	NC	WSC	Reduction (%)
G01	87	94	9	29	26	-9	27	17	-39
G02	147	129	-12	23	19	-17	26	19	-27
G03	78	111	41	26	22	-14	21	17	-20
G04	174	102	-42	22	23	3	26	18	-31
G05	124	114	-8	26	17	-32	25	16	-35
G06	181	147	-19	25	22	-12	23	18	-18
G07	124	104	-16	29	24	-16	27	16	-39
G08	77	199	159	29	23	-21	25	17	-32
G09	123	112	-9	22	22	-1	24	26	7
G10	198	77	-61	26	21	-17	23	16	-31
G11	184	93	-50	26	25	-2	24	18	-25
G12	94	150	59	26	26	-1	22	17	-22
G13	61	149	146	25	25	0	23	17	-28
G14	155	102	-34	24	22	-11	20	18	-10
G15	104	108	4	23	18	-19	23	21	-8
G16	108	114	6	31	16	-49	25	20	-20
G17	73	130	77	33	23	-30	21	15	-31
G18	108	181	67	27	18	-32	22	13	-43
G19	94	76	-19	18	22	24	24	16	-31
G20	77	112	46	30	25	-15	19	16	-18
G21	133	118	-11	21	25	16	18	17	-4
G22	111	115	4	26	22	-16	20	15	-25
G23	89	108	21	27	26	-2	20	18	-12
G24	103	111	7	21	22	6	22	17	-20
G25	76	89	18	28	23	-18	20	16	-18
G26	82	67	-19	35	27	-22	20	17	-17
G27	109	145	33	33	18	-46	24	17	-28
G28	149	112	-25	24	20	-17	19	16	-13
G29	121	166	37	41	22	-47	21	19	-10
G30	100	119	19	25	23	-9	19	15	-21
G31	119	207	74	25	21	-14	16	21	31
G32	102	100	-2	22	26	16	20	22	12
G33	99	76	-23	30	24	-21	25	18	-27
G34	115	87	-25	18	23	27	17	22	29
G35	82	104	26	40	26	-34	26	19	-26
G36	90	107	19	37	26	-31	24	16	-34

deficit occurred. Changes in flowering duration varied from 8% to -13%. The earliest flowering was noticeable for genotypes G22 (-13%), G23 (-12%), G32 (-10%), and G36 (-10%) (Table 2). Similar findings came from Alafari *et al*. (2024), who documented earlier flowering in rice genotypes under water-stress conditions. As displayed in Figure 1B, water stress caused a significant reduction in flag leaf area, indicating a morphological alteration linked with reduced photosynthetic efficiency, resulting in reduced yield.

Genotypes G17, G02, G07, G19, G36, and G20 showed a significant reduction in flag leaf area with a magnitude of >49% (Table 2). A comparable range of flag leaf area reduction (14%–45%) under water-stress conditions was also an outcome reported by El-Hashash *et al.* (2018). Plant height, decreased by 1%–34% under water-stress conditions, resulted in

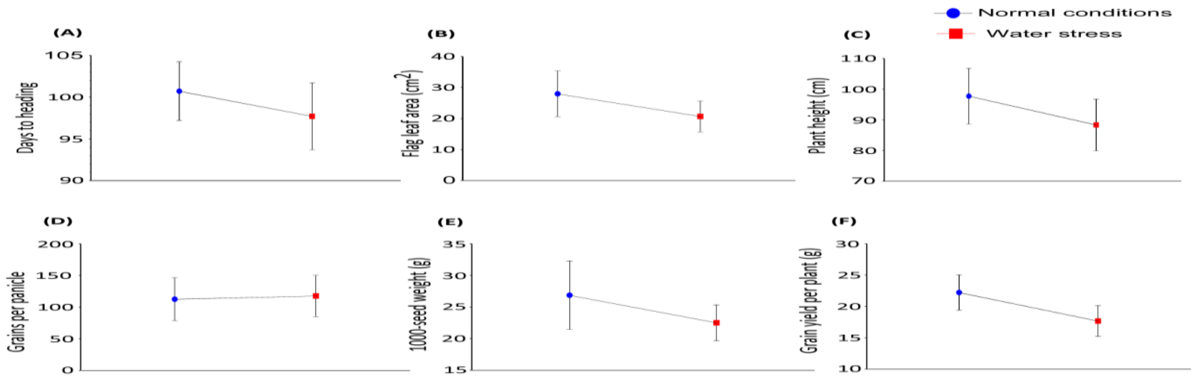

Figure 1. Impact of water stress on rice genotypes for days to heading (A), flag leaf area (B), plant height (C), grains per panicle (D), 1000-seed weight (E), and grain yield per plant (F), with vertical bars representing mean ±SD.

limited assimilate and biomass production, as depicted in Figure 1C. Higher depreciation for this trait appeared for genotypes G05 (-34%), G02 (-27%), G07 (-23%), and G27 (-21%) (Table 2). Alafari *et al.* (2024) also reported a similar pattern of reduction (6%–24%) in plant height among 12 rice genotypes. Likewise, Sadhukhan *et al*. (2024) and Islam *et al*. (2025) noted a considerable decline in plant height under water-stress conditions.

As presented in Figure 1D, water stress had a negative impact on the production of grains per panicle, amounting to 61% in the studied rice genotypes (Table 3). Genotypes G10 (-61%), G11 (-50%), and G04 (-42%) surfaced as the most severely affected genotypes for this trait under water-stress conditions. The 1000-seed weight showed a decline of 1%–49% under water-stress conditions, as detailed in Figure 1E, which subsequently resulted in impaired grain filling and yield loss. The sharpest decline regarding 1000-seed weight was evident for genotypes G16 (-49%), G29 (-47%), and G27 (-46%) (Table 3). Our findings aligned with those of El-Hashash *et al.* (2018), who observed a comparable reduction range (4%–22%) for 1000-seed weight. As presented in Figure 1F, water stress considerably reduced grain yield per plant (4%–43%) in most studied genotypes. The most drastic yield reduction was prevalent for G18 (-43%), G01 (-39%), G07 (-39%), and G05 (-35%) (Table 3). A similar pattern of grain yield decline also came from findings by Sathyaraj and Sabesan (2025), who recorded yield reduction in 20 rice genotypes from 42% to 60% under water-stress conditions.

Water-stress-tolerance profiling of the genotypes

Various stress tolerance indices based on grain yield under normal (Yp) and water-stress conditions (Ys) succeeded in calculating. Rice genotypes produced higher grain yield under normal conditions than in water-stress conditions, which was in agreement with the findings of Sathyaraj and Sabesan (2025). It is noteworthy to mention that low values for the stress susceptibility index (SSI) could be an effective gauge for water-stress-tolerance potential. Similarly, high values for yield index (YI), yield stability index (YSI), drought resistance index (DRI), stress tolerance index (STI), mean productivity index (MPI), geometric mean productivity (GMP), and harmonic mean (HM) are reliable indicators of water-stress tolerance potential (El-Hashash *et al.,* 2018; Adhikari *et al.,* 2019; Hooshmandi, 2019; Kandel *et al.,* 2022).

Genotypes G09, G31, G32, and G34 exhibited consistent performance based on the multiple stress selection indices, reaching classification as water-stress-tolerant genotypes. These genotypes have significant potential as valuable genetic resources for rice breeding programs targeting drought-prone regions. Genotype G09 (SSI = −0.36; STI = 1.23; MPI = 24.68; GMP = 24.67; YI = 1.45; YSI = 1.07; DRI = 1.55; HM = 24.65) and G32 (SSI = −0.59; STI = 0.90; MPI = 21.16; GMP = 21.12; YI = 1.27; YSI = 1.12; DRI = 1.42; HM = 21.09) exhibited superior performance under water-stress conditions compared with irrigated conditions. The yield reduction under irrigated conditions of these genotypes was, however, not drastic enough, thus making them more stable under both environments.

Genotypes G31 (SSI = −1.50; STI = 0.69; MPI = 18.68; GMP = 18.51; YI = 1.20; YSI = 1.31; DRI = 1.57; HM = 18.35) and G34 (SSI = −1.40; STI = 0.75; MPI = 19.45; GMP = 19.29; YI = 1.24; YSI = 1.29; DRI = 1.59; HM = 19.14) presented water-stress-tolerant profiles characterized by high YSI and DRI and moderate STI values. These genotypes were specifically more desirable for drought-prone environments than in irrigated conditions (Table 4).

Principal component analysis

The first and second principal components (PC1 and PC2, respectively) of the principal component analysis (PCA) based on grain yield under normal (Yp) and water-stress conditions (Ys) for stress tolerance indices displayed high eigenvalues of 5.98 and 3.97, respectively. PC1 and PC2 explained (PC1 = 59.8%; PC2 = 39.7%) the total variance among the stress tolerance indices. PC1 mostly had dominance from Ys and Yi, while PC2 consisted heavily of Yp and SSI (Table 5). Kandel *et al.* (2022) also reported the first and second PCs cumulatively explained total variation for stress tolerance indices, which was consistent with the results of this present study.

PCA revealed the stress tolerance indices based on grain yield served as an effective and reliable statistical tool for categorizing water-stress-tolerant genotypes. The bottom right quadrant of the PCA scatter plot contained highly water-stress-tolerant genotypes, such as G09, G31, G32, and G34, which had a strong association with Ys and stress tolerance indices, viz., YI, DRI, and YSI. The eigenvectors of these genotypes were further away from the origin, with positive PC1 and negative PC2 values.

Eleven rice genotypes, namely, G01, G02, G04, G06, G08, G11, G15, G16, G27, G33, and G35, had locations on the top right quadrant, with positive values for both PCs. The Yp and tolerance indices, such as HM, STI, GMP, and MP, expressed links with these genotypes. Genotypes G02, G16, and G35, positioned farther from the origin, have maximum divergence and were seemingly suitable for both irrigated and water-stress conditions.

The top left quadrant included eight genotypes: G05, G07, G10, G12, G13, G18, G19, and G36. These genotypes had negative and positive vectors for PC1 and PC2, respectively. The SSI revealed a correlation with this group of genotypes. Genotypes G05, G07, G19, and G36 had distant locations from the axis with greater divergence. These genotypes showed a better performance under irrigated conditions but were recognizably susceptible to water-stress conditions.

Genotypes located in the bottom left quadrant of the scatter plot had negative values for both PCs and showed no association with any stress tolerance index. These genotypes did not perform well under both conditions (Table 5, Figure 2). Sathyaraj and Sabesan (2025) studied 20 rice genotypes under both irrigated and drought conditions and identified a similar factor-loading pattern of various stress indicators for PC1 and PC2.

CONCLUSIONS

Water stress impaired the yield performance of the studied rice genotypes. However, rice genotypes G09, G31, G32, and G34 were distinct as water-stress-tolerant ones based on their high grain yield, desirable stress-tolerance index values, and PCA clustering pattern. These genotypes have strong potential for onward use in rice breeding programs to derive high-yielding, water-stress-tolerant rice cultivars. Moreover, these genotypes would serve as valuable genetic resources for utilization in future rice hybridization programs focusing on water-stress tolerance.

ACKNOWLEDGMENTS

The authors would like to thank the Rice Breeding Program, Department of Plant Breeding and Genetics, the University of Agriculture, Peshawar-Pakistan, for providing genetic material and research facilities. Extending heartfelt thanks also to the reviewers of the manuscript for their valuable suggestions, which helped well to improve the text and presentation of this manuscript.

Table 4. Water-stress tolerance indices of 36 rice genotypes based on grain yield per plant under normal (NC) and water-stress conditions (WSC).

Genotypes	Grain yield per plant (g)		Stress tolerance indices							
	NC	WSC	SSI	STI	MPI	GMP	YI	YSI	DRI	HM
G01	27.32	16.56	1.92	0.92	21.94	21.27	0.94	0.61	0.57	20.62
G02	25.70	18.69	1.33	0.97	22.19	21.91	1.06	0.73	0.77	21.64
G03	21.08	16.96	0.95	0.72	19.02	18.91	0.96	0.80	0.77	18.79
G04	25.66	17.72	1.51	0.92	21.69	21.32	1.00	0.69	0.69	20.96
G05	24.84	16.22	1.69	0.82	20.53	20.07	0.92	0.65	0.60	19.63
G06	22.53	18.46	0.88	0.84	20.49	20.39	1.04	0.82	0.86	20.29
G07	26.70	16.35	1.89	0.88	21.52	20.89	0.93	0.61	0.57	20.28
G08	25.20	17.11	1.57	0.87	21.16	20.76	0.97	0.68	0.66	20.38
G09	23.80	25.56	-0.36	1.23	24.68	24.67	1.45	1.07	1.55	24.65
G10	22.79	15.63	1.53	0.72	19.21	18.87	0.88	0.69	0.61	18.54
G11	24.26	18.17	1.23	0.89	21.22	21.00	1.03	0.75	0.77	20.78
G12	22.15	17.26	1.08	0.77	19.71	19.55	0.98	0.78	0.76	19.40
G13	23.07	16.55	1.38	0.77	19.81	19.54	0.94	0.72	0.67	19.27
G14	20.06	18.15	0.46	0.74	19.11	19.08	1.03	0.90	0.93	19.06
G15	23.07	21.19	0.40	0.99	22.13	22.11	1.20	0.92	1.10	22.09
G16	24.78	19.78	0.98	0.99	22.28	22.14	1.12	0.80	0.89	22.00
G17	21.33	14.78	1.50	0.64	18.06	17.76	0.84	0.69	0.58	17.46
G18	22.35	12.63	2.12	0.57	17.49	16.80	0.72	0.57	0.40	16.14
G19	23.69	16.28	1.53	0.78	19.98	19.64	0.92	0.69	0.63	19.30
G20	19.21	15.83	0.86	0.62	17.52	17.44	0.90	0.82	0.74	17.36
G21	18.11	17.30	0.22	0.63	17.70	17.70	0.98	0.96	0.94	17.69
G22	20.33	15.18	1.23	0.63	17.76	17.57	0.86	0.75	0.64	17.38
G23	19.97	17.53	0.60	0.71	18.75	18.71	0.99	0.88	0.87	18.67
G24	21.61	17.24	0.99	0.75	19.43	19.31	0.98	0.80	0.78	19.18
G25	19.58	16.13	0.86	0.64	17.86	17.77	0.91	0.82	0.75	17.69
G26	20.29	16.84	0.83	0.69	18.57	18.48	0.95	0.83	0.79	18.41
G27	24.13	17.32	1.38	0.85	20.73	20.44	0.98	0.72	0.70	20.16
G28	18.66	16.25	0.63	0.61	17.46	17.41	0.92	0.87	0.80	17.37
G29	20.87	18.78	0.49	0.79	19.83	19.80	1.06	0.90	0.96	19.77
G30	18.86	14.93	1.02	0.57	16.90	16.78	0.85	0.79	0.67	16.67
G31	16.19	21.16	-1.50	0.69	18.68	18.51	1.20	1.31	1.57	18.35
G32	19.95	22.36	-0.59	0.90	21.16	21.12	1.27	1.12	1.42	21.09
G33	25.03	18.30	1.31	0.93	21.66	21.40	1.04	0.73	0.76	21.14
G34	17.01	21.88	-1.40	0.75	19.45	19.29	1.24	1.29	1.59	19.14
G35	25.92	19.18	1.27	1.01	22.55	22.30	1.09	0.74	0.80	22.05
G36	23.77	15.68	1.66	0.76	19.73	19.31	0.89	0.66	0.59	18.90
Grand mean	22.22	17.67	0.93	0.79	19.94	19.72	1.00	0.81	0.83	19.51

SSI = Stress susceptibility index; STI = Stress tolerance index; MPI = Mean productivity index; GMP = Geometric mean productivity; YI = Yield index; YSI = Yield stability index; DRI = Drought resistant index, and HM = Harmonic mean.

Table 5. Eigenvalue, variance, cumulative proportion, loadings of grain yield (Yp and Ys), and water-stress tolerance indices of 36 rice genotypes.

Components	PC1	PC2
Eigen value	5.98	3.97
Variance (%)	59.80%	39.70%
Cumulative Proportion	59.8	99.5
Stress tolerance indices		
Ys	0.391	-0.144
Yp	0.097	0.484
SSI	-0.211	0.428
STI	0.357	0.243
MP	0.340	0.278
GMP	0.356	0.248
YI	0.391	-0.144
YSI	0.211	-0.428
DRI	0.300	-0.338
HM	0.368	0.216

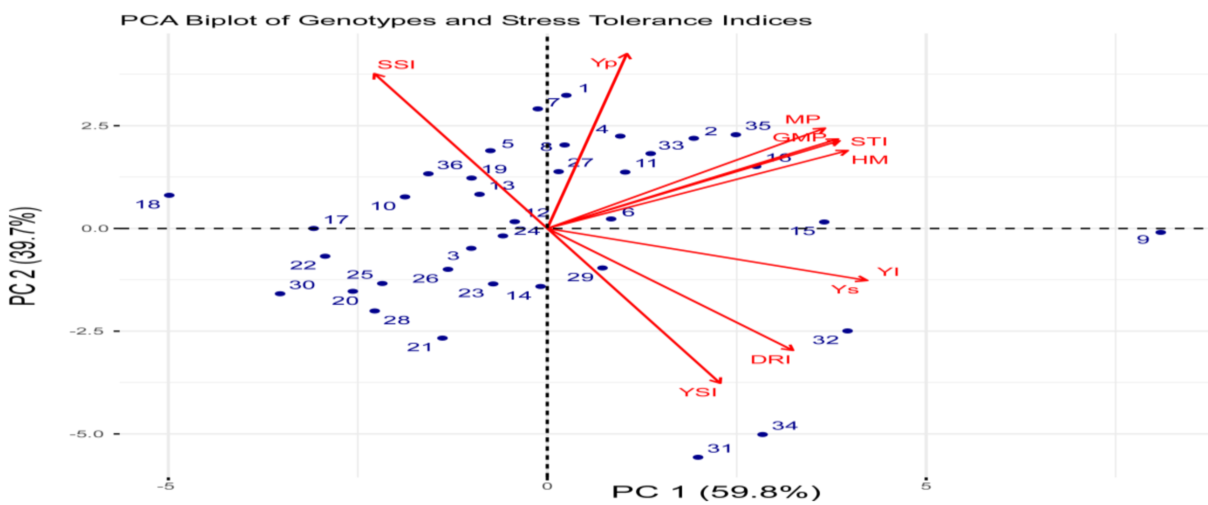

Figure 2. Scatter biplot of water-stress tolerance indices of 36 rice based on grain yield under normal (Yp) and water-stress conditions (Ys), where SSI = Stress susceptibility index; STI = Stress tolerance index; MPI = Mean productivity index; GMP = Geometric mean productivity; YI = Yield index; YSI = Yield stability index; DRI = Drought resistant index, and HM = Harmonic mean.

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