JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2024, 25(7), 371–383
https://doi.org/10.12911/22998993/188881
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.05.13
Accepted: 2024.05.24
Published: 2024.06.01

Evaluation of Drought Resistance and Quality of Different Rice Hybrid Combinations

Yiru Li[1,2], Muhammad Ahmad Hassan[2,3], Qian Zhu[2,3], WuyunFang[2,3], Yueming Yi[4], Sumei Duan[1], Haibing Yu[1], Shimei Wang[2,3*]

[1] Anhui Science and Technology University, Fengyang 233100, China
[2] Rice Research Institute, Anhui Academy of Agricultural Sciences, Hefei 230031, China
[3] Anhui Province Key Laboratory of Rice Germplasm Innovation and Molecular Improvement, Hefei 230031, China
[4] Propaganda Department of the People's Government of Anhui Province, Zongpu Town, Fengyang 233100, China
* Corresponding author's e-mail: wangshimei0551@163.com

ABSTRACT

Rice is an integral component of the daily food consumptions in China. Drought stress diminishes rice productivity and deteriorates its quality. To further improve the identification and selection system of drought-tolerant rice varieties, this experiment used 130 new rice hybrid combinations as research materials and water stress was carried out during the whole life span, with normal water management as the control, so as to construct a synergistic evaluation standard of drought-tolerance of rice in terms of yield and quality by examining the characteristics of plant height, fruiting rate, yield per plant, and quality. The study showed that (1) the coefficients of variation of the drought tolerance coefficients of the 11 indexes ranged from 3.50% to 44.35%, with the largest coefficient of variation being the yield per plant at 44.35% and the smallest being the grain length at 3.50%. According to the principal component analysis, the cumulative contribution of the first four principal components was 73.022%, which were the total number of grains, the number of solid grains, the effective panicles and plant height. The correlation analysis showed that the drought tolerance composite evaluation value was extremely significantly correlated with plant height, effective panicles, total grain number, number of solid grains, fruiting rate, thousand grain weight and grain width. Based on the results of stepwise regression analysis, the number of grains, plant height and thousand grain weight can be used as drought-resistant identification indexes. (2) Based on the variation characteristics of protein, brown rice rate, refined rice rate, whole refined rice rate and straight-chain starch content, 50 high-quality combinations were selected. The results of cluster analysis showed that the 50 rice combinations were divided into three groups, Group I strong drought-resistant with materials HD009, HD024, HD171, HD207, HD432, HD447, HD0451, a total of 7 materials up to the first level of rice indicators; Group II medium drought-resistant with 21 materials up to the first level of rice indicators; Group III drought-sensitive material HD522 up to the first level of rice indicators.

Keywords: rice, drought-resistant, drought stress, quality, selection system

INTRODUCTION

Rice is a key source of nourishment worldwide, and more than 60% of China's population consumes it as their primary food (Yang et al., 2015). Water is critical for developing rice (N'guessan et al., 2023). Rice consumes 70% of all agricultural water, making it the most water-intensive crop (Jiang et al., 2023). Due to increasing global warming and water scarcity, drought has become a major abiotic stress impacting optimal rice growth and drastically limiting its yield and quality (Cordell et al., 2009). Rice yield and quality are critical factors defining world food security (Zhang et al., 2020). Water scarcity-induced droughts impair the capacity of plants to grow and develop normally (Hassan et al., 2023), leading to declined grain yield and quality (Salgotra and Chauhan, 2023). The challenge for researchers in the past few years has been to breed rice varieties that are drought-resistant, high-yielding, and of excellent quality. The quantification of accurate drought resistance to assess the adaptive capacity of 'drought tolerance' in different varieties is considered an important basis for improving rice productivity (Wang et al., 2018).

Drought resistance in rice is a complex phenomenon that is influenced by multiple factors interacting with each other (i.e., frequency of rainfall, rate of evaporation and soil water content/capacity) (Oladosu et al., 2019); apart from it, many factors limit its evaluation and explorations, such as fertility period, identification indexes, evaluation methods, etc. It is difficult to accurately evaluate a single or a small number of indexes, and it should be assessed comprehensively using various indexes (Lv et al., 2019). Moisture is a crucial factor influencing rice quality during the reproductive development stage; hence, studying and understanding how sensitive rice quality is to moisture will aid in mitigating the negative impacts of drought. According to Hou et al. (2023), drought stress treatment decreased the complete rice kernel, straight-chain starch contents, branched-chain starch contents, straight-chain starch/branched-chain starch ratio, gel consistency, and disintegration in rice while increasing green grains, chalky rice grains, protein content, and amylose content, compared to irrigated rice. Wang et al. (2018a) stated that dry planting and dry management have significantly improved the content of straight-chain starch, the rate of polished rice, and the rate of whole polished rice, all of which have positive effects on rice quality. In this research study, we've taken 130 new rice hybrid combinations as experimental materials, carried out drought stress during their growth cycle, and explored the differences in drought tolerance capacity among the different hybrids. We've studied the effects of drought stress treatments on their yield, quality traits, and starch characteristics. Drought coefficient, affiliation, drought resistance comprehensive evaluation (comparative screening of resistant high yield and quality hybrids), correlation, cluster analysis, and other analytical techniques have all been used to build an identification and selection system that can simultaneously examine the yield and quality of the rice hybrid combinations, as well as provide references for the screening, selection, and breeding of water-efficient, water-saving, and drought-resistant rice varieties.

MATERIALS AND METHODS

Plant material and growth conditions

The test materials of 130 new rice hybrid combinations were provided by the rice research institute of Anhui academy of agricultural sciences (RRI-AAAS) for evaluating drought resistance and quality of rice. The experiment was conducted at the Hainan Lingshui Experimental Base of Anhui Academy of Agricultural Sciences in 2020. It was conducted in a large field area with two water treatments, well-watered and dry conditions (drought). Each experimental unit comprised 5 rows with 10 plants with a 20 × 26 cm spacing between rows and plants. Each experimental unit was replicated 3 times. The paddy field was managed according to local husbandry management practices. The dry field was naturally dried after the rice was transplanted. The artificial water supply was resumed after observing the 50% of wilted leaves in the paddy field (Fig. 1).

Measurements

Seed sampling was carried out when the crop reached the maturity stage; 5 single plants were randomly selected from each experimental unit.

Agronomic traits

The following agronomic traits were examined: plant height, effective panicles, panicle length, total number of grains per panicle, productive grains per panicle, seed-setting rate, 1000-grain weight, yield of a single plant, grain length*, and grain width* (*grain length and width were measured by seed meter TPKZ-2).

Quality traits

This study mainly examined four quality traits, including brown rice rate, refined rice rate, whole refined rice rate, and straight-chain amylose contents of the participating hybrid combinations. The paddy processing quality was measured using a brown rice machine (THU35-C-C), a refined rice machine (JMNJ-3), and a broken rice separator (FQS-13X20) to determine the brown rice rate, refined rice rate, and whole refined rice rate, respectively.

Data processing and analysis

Data processing were carried out by evaluating the drought tolerance coefficient, drought resistance affiliation value, weighting value, drought resistance comprehensive ability evaluation value (Wang et al., 2017; Zhang et al., 2018).

Drought tolerance coefficient = trait value under drought stress/trait value under normal irrigation × 100%.

Drought affiliation function value:

$$F(Xi) = (Xi - Xi_{min})/(Xi_{max} - Xi_{min})\ i \in [1, n] \quad (1)$$

where: Xi is the drought treatment value of each indicator, $F(Xi)$ is each indicator's drought affiliation function value, and Xi_{max} and Xi_{min} are the maximum and minimum of the drought treatment value, respectively.

The weight value q and the comprehensive evaluation value D of the integrated drought tolerance were calculated by referring to the method of related research.

$$q = {}^{Vi}/_{\sum Xi} \quad (2)$$

$$D = \sum_{i=1}^{n}[f(Xi \cdot q)]\ i \in [1, n] \quad (3)$$

where: Vi is the standard deviation coefficient of each index, where $\sum xi$ is the sum of the mean values of each index of all germplasm materials, and q is the weight of each index. The D value is the comprehensive evaluation value of drought resistance of different materials.

Data was analyzed using Microsoft Office Excel2010 software; principal component and cluster analysis were performed using SPSS Statistics26 software; and systematic cluster analysis was performed using the Euclidean distance clustering method using Origin 2021 software.

RESULTS

Analysis of the drought coefficient of each index in different hybrid combinations

Drought coefficient difference analysis of agronomic and yield indices

Drought coefficient difference analysis was performed for each indicator in order to examine the changes of various indices under drought stress in different hybrid combinations. The results showed that the standard deviation, mean, and coefficient of variation of the drought tolerance for each agronomic and yield indices changed to a large extent (Table 1). Among these, the mean value of the aspect ratio was the largest at 1.033, and the mean value of the yield of the single plant was the smallest at 0.460. The coefficients of variation for each trait of the hybrid rice combinations ranged from 3.50% to 44.35%, and the coefficient of variation for the yield of a single plant

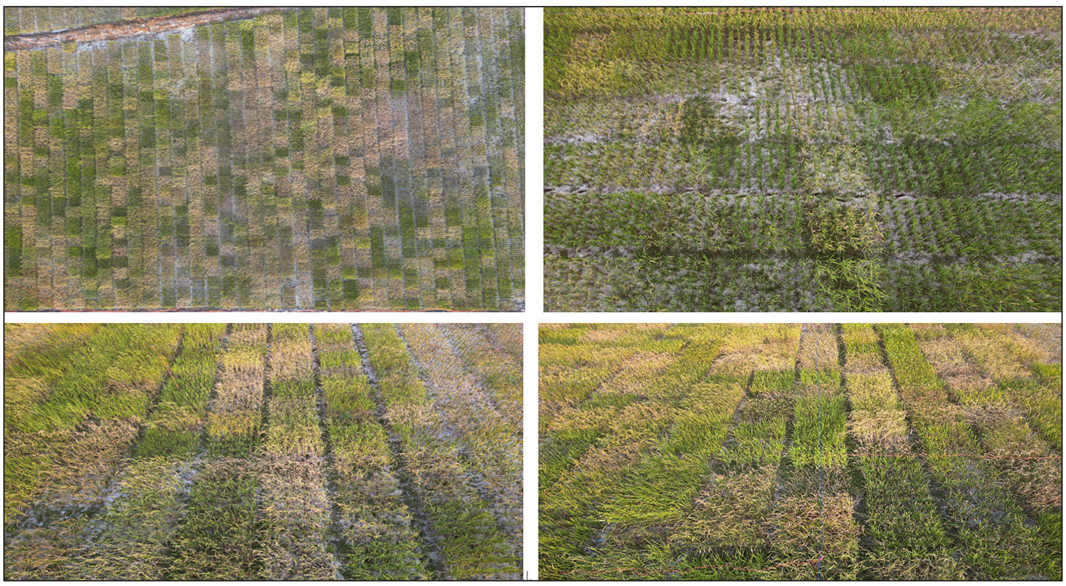

Figure 1. Aerial images of the experimental field

Table 1. Drought tolerance coefficients for individual indicators

Index	Drought tolerance factor mean	SD	CV(%)
Plant height	0.842	0.066	7.80%
Effective panicles number	0.762	0.211	27.70%
Panicle length	1.001	0.061	6.10%
Grain length	0.978	0.034	3.50%
Grain width	0.949	0.055	5.70%
Grain length-width ratio	1.033	0.043	4.10%
Grain yield plant	0.460	0.204	44.35%
Grains per panicle	0.711	0.242	34.00%
Filled grains per panicle	0.535	0.213	39.90%
Seed setting rate	0.747	0.127	17.00%
1000 – grain weight	0.839	0.088	10.50%

was the largest at 44.35%, which indicated that the variation of the phenotypic traits in this phenotypic combination was between 3.50% and 44.35%. The coefficient of variation of single plant yield was the largest at 44.35%, indicating that the degree of variation of this phenotypic trait was high and the stability was poor; the coefficient of variation of grain length was the smallest at 3.50%, indicating that the degree of variation of this phenotypic trait was low and the stability was good. In summary, drought stress affected each index to different degrees, and the differences were significant

Principal component analysis of drought resistance coefficients of agronomic and yield indicators in different hybrid combinations

Principal component analysis was performed to analyze the drought tolerance coefficients of all indicators (Fig. 2, Table 2). We found four principal components with eigenvalues greater than 1, with a cumulative variance contribution rate of 73.022%; of these, the eigenvalue of principal component 1 was 3.432, with a contribution rate of 31.197%; these components were primarily determined by the total number of grains, number of real grains and number of effective panicles,

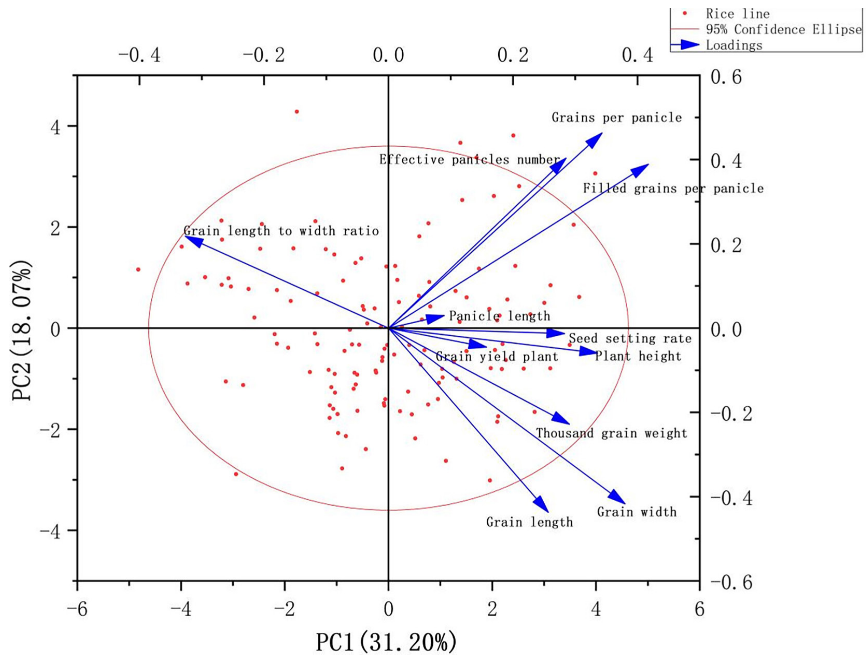

Figure 2. Principal component analysis of drought resistance coefficient of rice lines and indexes under drought stress

Table 2. Principal component analysis of drought tolerance coefficients of rice indicators under drought stress

Index	Ingredient factors			
	1	2	3	4
Plant height	0.287	0.433	0.068	0.649
Number of effective panicles	0.828	0.086	0.013	-0.084
Panicle length	0.016	-0.094	-0.039	0.867
Grains per panicle	0.924	0.04	0.031	0.154
Filled grains per panicle	0.868	0.036	0.388	0.169
Seed setting rate	0.178	-0.003	0.823	0.102
1000 – grain weight	-0.018	0.271	0.775	0.082
Grain yield per plant	0.076	0.077	0.477	-0.108
Grain length	-0.223	0.638	0.319	0.315
Grain width	0.043	0.966	0.197	0.083
Grain length-width ratio	-0.236	-0.831	-0.018	0.158
Eigenvalue	3.432	2.098	1.27	1.232
Contribution rate (%)	31.197	19.074	11.548	11.203
Cumulative contribution (%)	31.197	50.271	61.818	73.022

with component coefficients of 0.924, 0.868 and 0.828, respectively. The second principal component was grain length and grain width, with component coefficients of 0.638 and 0.966, respectively, with a contribution rate of 19.074%. Seed setting rate and 1,000 – grain weight were the third principal components, with component coefficients of 0.823 and 0.775, respectively, and a contribution rate of 11.543%. The fourth principal component was the length of the panicle and plant height, with the component coefficients of 0.867 and 0.649, respectively, and the contribution rate of 11.203%.

Mean value of affiliation function, comprehensive evaluation D value, and drought resistance evaluation of agronomy and yield indicators

The mean values of the affiliation function and the comprehensive evaluation D value for 11 traits, i.e., plant height, effective panicle, panicle length, and total grain number, were used as evaluation indexes for the assessment of drought resistance in 130 hybrid rice combinations. The affiliation values of the relevant indexes (such as single plant yield, plant height, and 1000 – grain weight) were closely related to drought resistance. The size of the mean value of the affiliation function of the indices was utilized to reflect the strength of the drought resistance of the rice (Table 3). According to the order of the size of the mean value of the affiliation function, yield ranked first. The results show that according to the size of the average value of the affiliation function, HD198 has the strongest drought resistance, and HD304 has the worst drought resistance. According to the comprehensive evaluation D value, HD198 has the highest comprehensive evaluation value of 0.828, indicating strong drought resistance; HD304 has the lowest comprehensive evaluation value of 0.343, indicating weak drought resistance; this is basically consistent with the results of the affiliation function value evaluation.

Correlation between comprehensive evaluation D value and drought tolerance coefficients

The correlation between the comprehensive evaluation D value and the drought tolerance coefficient was analysed (Figure 3). The correlation coefficients of comprehensive evaluation D-value with plant height, effective panicle, total grain number, grain number, seed setting rate, 1000 – grain weight, and grain width were highly significant ($P < 0.001$), ranging from 0.36–0.64. The correlation coefficients with grain length were also highly significant, with a range of 0.27. The correlation coefficients with panicle length and yield of a single plant were not significant. After drought stress, the correlation degree between each agronomic trait index and drought resistance of rice was in the following order: filled grains per panicle > plant height > grains per

Table 3. Mean value of the affiliation function, D-value of comprehensive evaluation, and drought tolerance evaluation of rice indicators

Hybrids	Membership function mean	Sort	D	Sort	Hybrids	Membership function mean	Sort	D	Sort
HD009	0.753	6	0.927	15	HD273	0.498	82	0.610	80
HD011	0.561	55	0.691	59	HD279	0.606	40	0.755	42
HD017	0.651	28	0.808	31	HD281	0.481	95	0.613	79
HD024	0.745	8	0.992	8	HD286	0.458	104	0.563	91
HD032	0.566	50	0.633	70	HD291	0.767	5	0.930	14
HD033	0.672	22	0.874	20	HD295	0.790	3	1.007	6
HD034	0.731	12	0.957	11	HD296	0.553	60	0.552	94
HD036	0.614	37	0.732	48	HD299	0.656	25	0.780	37
HD043	0.523	72	0.621	73	HD300	0.562	54	0.664	65
HD048	0.487	91	0.635	69	HD302	0.478	98	0.586	84
HD050	0.617	35	0.832	27	HD304	0.318	130	0.343	130
HD053	0.409	114	0.530	102	HD309	0.529	69	0.581	85
HD056	0.480	96	0.651	66	HD310	0.422	110	0.536	100
HD061	0.774	4	1.094	2	HD314	0.401	116	0.384	125
HD062	0.527	70	0.765	40	HD322	0.383	122	0.377	126
HD066	0.596	43	0.796	34	HD325	0.340	129	0.395	124
HD068	0.554	58	0.707	55	HD326	0.459	103	0.489	114
HD074	0.547	64	0.725	50	HD327	0.392	120	0.458	116
HD076	0.600	41	0.753	43	HD330	0.490	90	0.505	109
HD080	0.595	44	0.847	22	HD332	0.506	79	0.574	86
HD084	0.501	81	0.591	83	HD336	0.509	76	0.617	76
HD094	0.532	68	0.615	77	HD341	0.613	38	0.724	51
HD098	0.492	88	0.503	110	HD342	0.515	74	0.571	88
HD103	0.496	83	0.617	75	HD343	0.566	52	0.685	62
HD109	0.451	106	0.516	108	HD345	0.647	29	0.834	26
HD110	0.346	128	0.400	123	HD355	0.592	45	0.702	56
HD111	0.404	115	0.520	107	HD356	0.492	87	0.621	74
HD114	0.479	97	0.573	87	HD358	0.466	101	0.526	105
HD121	0.399	117	0.493	113	HD371	0.592	46	0.838	24
HD136	0.570	48	0.830	28	HD372	0.583	47	0.713	54
HD150	0.655	26	0.883	19	HD376	0.451	105	0.566	90
HD159	0.554	57	0.749	45	HD378	0.551	61	0.740	47
HD165	0.448	107	0.623	72	HD379	0.392	121	0.424	121
HD167	0.430	109	0.554	93	HD380	0.417	112	0.447	119
HD168	0.493	86	0.777	38	HD382	0.490	89	0.550	95
HD169	0.420	111	0.548	98	HD406	0.374	123	0.498	112
HD171	0.692	19	0.905	16	HD411	0.358	126	0.481	115
HD177	0.483	94	0.524	106	HD422	0.394	118	0.449	117
HD178	0.410	113	0.547	99	HD430	0.719	16	0.997	7
HD180	0.546	65	0.647	68	HD432	0.671	23	0.986	9
HD183	0.486	92	0.549	97	HD433	0.545	66	0.610	81
HD184	0.570	49	0.682	63	HD437	0.484	93	0.727	49
HD198	0.828	1	1.097	1	HD442	0.544	67	0.697	58
HD205	0.680	20	0.829	29	HD445	0.563	53	0.744	46
HD207	0.715	17	0.895	17	HD446	0.725	13	0.885	18
HD208	0.494	85	0.614	78	HD447	0.435	108	0.448	118

HD212	0.507	77	0.568	89	HD449	0.652	27	0.821	30
HD213	0.566	51	0.687	60	HD451	0.741	9	0.949	12
HD215	0.549	62	0.632	71	HD453	0.616	36	0.757	41
HD218	0.496	84	0.555	92	HD459	0.553	59	0.702	57
HD221	0.741	10	0.984	10	HD472	0.392	119	0.375	127
HD222	0.751	7	1.078	3	HD474	0.525	71	0.501	111
HD225	0.462	102	0.529	104	HD482	0.356	127	0.347	128
HD228	0.507	78	0.599	82	HD485	0.627	32	0.714	53
HD230	0.557	56	0.678	64	HD487	0.674	21	0.801	33
HD232	0.611	39	0.806	32	HD492	0.808	2	1.048	4
HD233	0.642	30	0.769	39	HD495	0.736	11	0.944	13
HD234	0.510	75	0.549	96	HD497	0.708	18	0.838	25
HD241	0.360	125	0.405	122	HD501	0.627	33	0.784	35
HD243	0.476	99	0.535	101	HD503	0.598	42	0.750	44
HD248	0.656	24	0.844	23	HD510	0.638	31	0.783	36
HD255	0.363	124	0.425	120	HD512	0.724	15	0.850	21
HD262	0.549	63	0.686	61	HD522	0.472	100	0.346	129
HD267	0.725	14	1.022	5	HD524	0.620	34	0.715	52
HD270	0.520	73	0.649	67	4	0.504	80	0.530	103

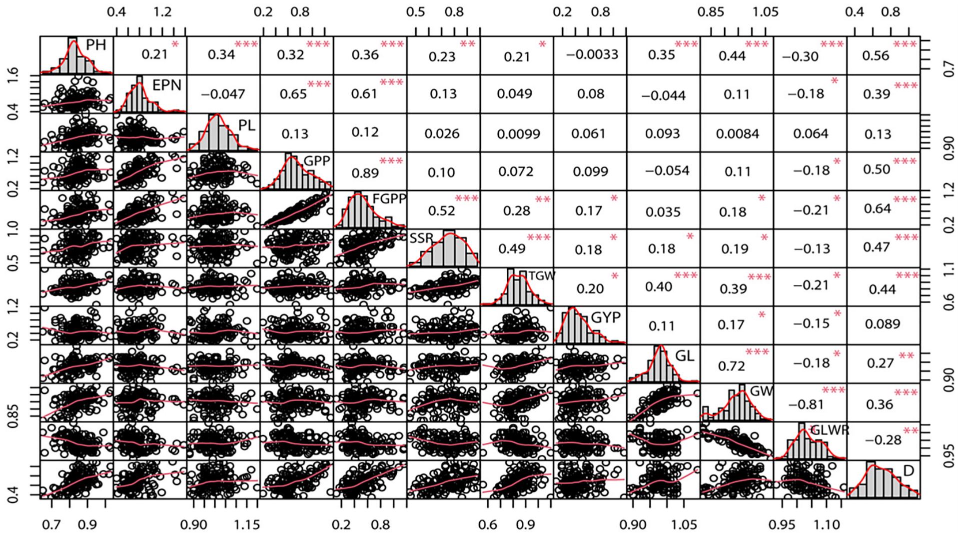

Figure 3. Correlation analysis of various indicators of rice under drought stress.
*, **, ***: denote significant differences at 0.05, 0.01, and 0.001 levels, respectively. pH: plant height, EPN: effective panicle number, PL: panicle length, GPP: grains per panicle, FGPP: Filled grains per panicle, SSR: seed setting rate, TGW: 1000-grain weight, GYP: grain yield plant, GL: grain length, GW: grain width, GLWR: grain length to width ratio

panicle > seed setting rate > 1000-grain weight > effective panicle number > grain width > grain length > grain length-width ratio > panicle length > grain yield per plant. There was also a correlation between the agronomic shape indices, which indicated that the D-value better reflects the drought resistance and can be used for evaluating the drought resistance of hybrid rice.

Stepwise regression analysis of drought coefficients and comprehensive evaluation D value of each index under drought conditions

The drought coefficients of each index would differ due to the different characteristics of each hybrid after the drought stress. Stepwise regression analysis was used to establish the optimal regression equation with the D value of the comprehensive evaluation of drought resistance as the dependent variable and the drought coefficients of the individual indexes as the independent variables:

$$Y = -0.746 + 0.963 \cdot X1 + 0.378 \cdot X9 + 0.488 \cdot X11 \quad (4)$$

The coefficient of determination was $R2 = 0.596$. In this regression equation, $X1$, $X9$, and $X11$ were the plant height, the number of effective grains, and the 1000-grain weight under drought stress in rice, respectively. Therefore, there were three drought tolerance indexes, $X1$, $X9$, and $X11$, which can be used to characterize the drought tolerance of rice hybrids under drought stress.

Quality evaluation of different hybrid rice combinations under drought stress

According to the GB/T21719-2008 standard test for the 130 test materials for the whole refined rice rate single judgment as follows: 112 first-class rice, 6 second-class rice, 5 third-class rice, 7 ordinary rice; straight chain starch single judgment as follows: 37 first-class rice, 12 second-class rice, 3 third-class rice, 78 ordinary rice.

A total of 50 high-quality combinations have been screened out in accordance with NY/T593-2021 "quality of edible rice varieties," based on standards of brown rice rate, refined rice rate, whole refined rice rate, straight chain starch content, and other indicators. These combinations correspond to first-class rice 35, second-class rice 11, and third-class rice 4. As shown in Figure 4 and Table 4, the 50 rice materials were evaluated, and cluster analyses were categorized into three groups: 1) strong drought-resistant, 2) medium drought-resistant, and 3) drought-sensitive. Among them, there are materials HD009, HD024, HD171, HD207, HD432, HD447, and HD0451, a total of seven hybrid rice combinations for the strong drought-resistant first-grade rice, material HD034 for the strong drought-resistant second-grade rice; medium drought-resistant in the first-grade 27, second-grade 10, third-grade 4; material HD522 for the drought-sensitive first-grade rice. Figure 5 exhibited top 5 strong drought-resistant types and 5 medium drought-resistant types.

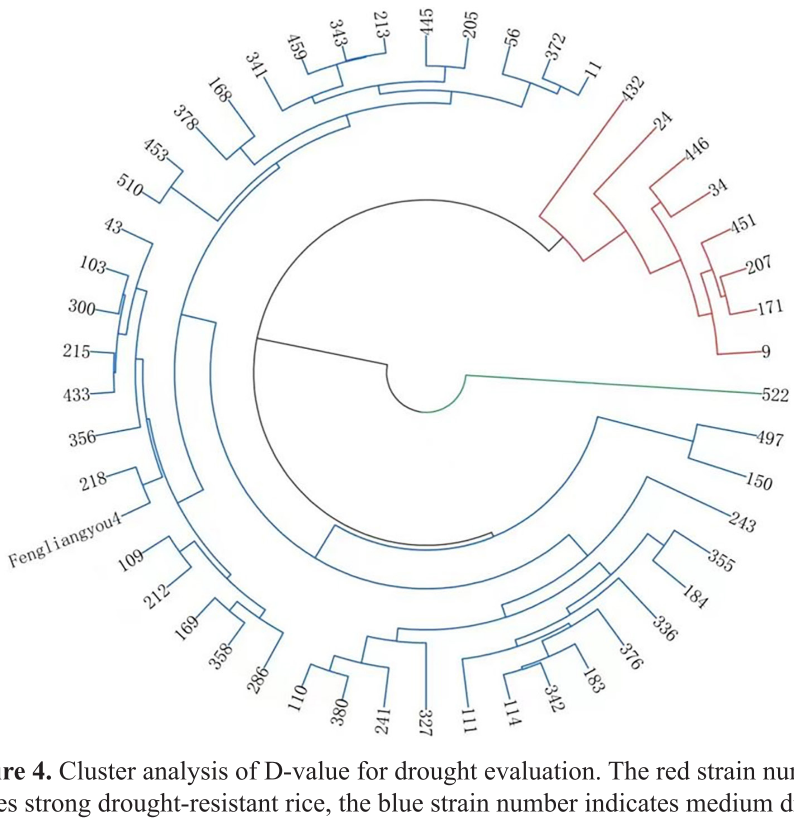

Figure 4. Cluster analysis of D-value for drought evaluation. The red strain number indicates strong drought-resistant rice, the blue strain number indicates medium drought-resistant rice, and the green strain number indicates drought-sensitive rice.

Table 4. Quality evaluation of different hybrid rice combinations

Hybrids	Carbohydrate	Amylose %	Head rice rate %	Brown rice rate %	Refined rice rate %	Rice quality grade	Drought resistant type
HD009	8.30	14.56	63.90	79.47	72.33	1	strong drought-resistant
HD024	8.17	16.17	61.75	80.35	70.17	1	strong drought-resistant
HD034	6.68	19.98	63.24	80.11	71.00	2	strong drought-resistant
HD171	6.97	13.50	69.28	79.13	72.60	1	strong drought-resistant
HD207	7.56	13.31	65.03	78.97	71.47	1	strong drought-resistant
HD432	6.67	15.11	69.67	78.56	72.68	1	strong drought-resistant
HD446	6.01	15.81	65.69	79.61	72.10	1	strong drought-resistant
HD451	7.72	13.48	66.97	79.36	72.10	1	strong drought-resistant
HD011	7.82	13.88	54.86	80.06	72.90	3	medium drought-resistant
HD043	7.96	13.84	69.21	77.89	71.22	1	medium drought-resistant
HD056	7.17	17.08	68.49	79.08	71.35	1	medium drought-resistant
HD103	6.91	18.93	66.72	79.38	72.07	2	medium drought-resistant
HD109	6.40	19.03	64.38	79.15	72.24	2	medium drought-resistant
HD110	6.40	17.42	65.33	78.43	70.85	1	medium drought-resistant
HD111	8.24	17.20	70.99	78.94	72.61	1	medium drought-resistant
HD114	7.33	18.97	72.68	81.36	74.68	2	medium drought-resistant
HD150	7.78	15.35	66.26	77.32	71.44	1	medium drought-resistant
HD168	6.70	19.81	61.50	78.43	71.00	2	medium drought-resistant
HD169	6.55	13.36	68.08	78.78	72.01	1	medium drought-resistant
HD183	7.92	13.46	68.43	77.93	71.64	1	medium drought-resistant
HD184	6.80	14.05	69.85	78.72	72.32	1	medium drought-resistant
HD205	7.18	16.74	69.31	78.60	72.57	1	medium drought-resistant
HD212	7.21	14.37	69.94	78.42	71.89	1	medium drought-resistant
HD213	6.99	13.98	68.65	78.69	71.17	1	medium drought-resistant
HD215	7.35	13.24	69.79	78.68	72.04	1	medium drought-resistant
HD218	7.78	15.38	70.90	78.42	72.19	1	medium drought-resistant
HD241	7.50	14.22	69.63	78.65	71.43	1	medium drought-resistant
HD243	7.59	13.42	70.71	78.65	72.40	1	medium drought-resistant
HD286	7.38	13.45	69.74	80.08	72.43	1	medium drought-resistant
HD300	6.43	13.31	68.46	78.94	72.04	1	medium drought-resistant
HD327	7.73	13.05	66.19	78.36	71.81	1	medium drought-resistant
HD336	6.75	13.69	69.36	79.60	72.75	1	medium drought-resistant
HD341	6.71	19.37	64.83	79.69	72.35	2	medium drought-resistant
HD342	6.68	19.03	65.29	80.26	71.85	2	medium drought-resistant
HD343	6.14	20.77	66.76	79.94	71.71	3	medium drought-resistant
HD355	6.72	19.29	65.10	79.47	71.60	2	medium drought-resistant
HD356	6.68	19.68	68.17	79.75	73.14	2	medium drought-resistant
HD358	7.56	20.31	66.74	79.69	71.76	3	medium drought-resistant
HD372	5.45	18.89	57.58	79.57	71.07	2	medium drought-resistant
HD376	7.07	16.16	52.42	80.25	72.69	3	medium drought-resistant
HD378	6.17	16.59	61.39	79.88	72.65	1	medium drought-resistant
HD380	6.41	18.93	57.51	79.63	71.79	2	medium drought-resistant
HD433	7.08	13.91	64.82	80.72	72.90	1	medium drought-resistant
HD445	5.98	13.03	66.01	79.94	71.78	1	medium drought-resistant
HD453	7.97	16.32	70.36	80.25	73.13	1	medium drought-resistant
HD459	7.54	16.48	66.65	80.63	72.58	1	medium drought-resistant
HD497	8.20	13.20	64.21	78.33	72.21	1	medium drought-resistant
HD510	7.57	14.35	64.94	79.21	72.71	1	medium drought-resistant
Fengliangyou 4	9.84	22.70	68.28	78.60	70.92	1	medium drought-resistant
HD522	6.59	14.98	70.93	79.33	73.19	1	drought-sensitive

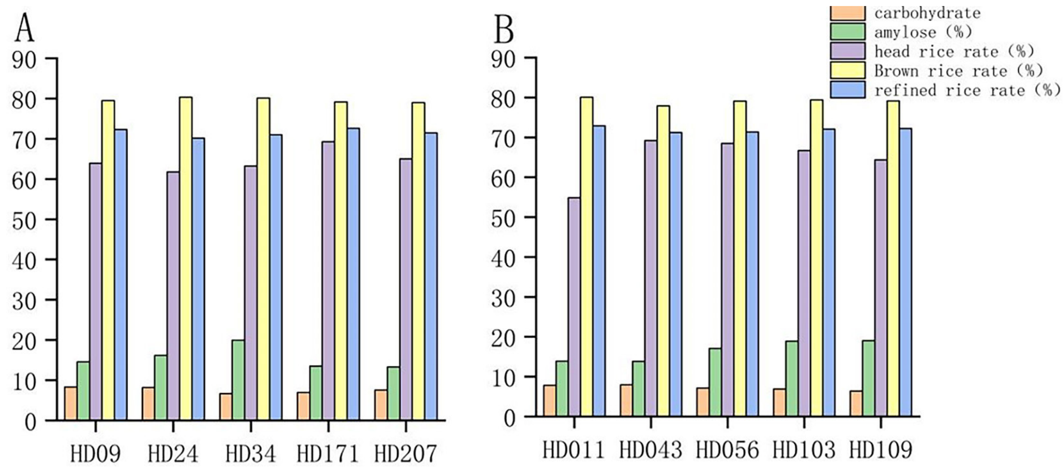

Figure 5. Processing quality and appearance quality of hybrid combinations. The rice strains in (A) are a strong drought-resistant type, and the rice strains in (B) are a medium drought-resistant type.

DISCUSSION

Research on the screening and analysis of various indicators of drought resistance in different hybrid combinations

The identification and screening of indicators of drought tolerance in rice have become the focus of attention for many researchers (Hu et al., 2006; Qin et al., 2013; Wang et al., 2005); however, the screening of identification indicators varies due to the selection of drought-tolerant materials, differences in target traits, and the diversity of water stress treatments. Previous researchers have explored the relationship between drought tolerance and related traits, such as phenotype and yield, at various times in rice. Mau et al. (2019) concluded that yield as an indicator of drought tolerance is an effective method for selecting genotypes combining drought tolerance and high-yield potential. In this study, 130 hybrid rice combinations were used for the identification and evaluation of drought tolerance indexes. The related agronomic and yield traits were examined. The difference analysis of drought tolerance coefficients of the traits was carried out, and the standard deviation, mean, and coefficient of variation of drought tolerance coefficients of the indexes changed to a larger extent. In order to identify and assess the drought resistance of hybrid rice combinations, the mean value of the affiliation function of each trait index and the thorough evaluation of the D-value have higher accuracy and reliability. This can more effectively make up for the inadequacy of the drought resistance coefficient and drought resistance index to carry out drought resistance evaluation with a single index (Zhang et al., 2018). Zhao et al. (2019) comprehensively evaluated the drought resistance of the new wheat germplasm through the principal component analysis, affiliation function analysis, and other comprehensive evaluations of the drought resistance of the new wheat germplasm. Li et al. (2023) assessed yellow clover's drought resistance identification using subordinate function analysis. The 11 variables in this study were reduced to 4 representative indicators by principal component analysis, yielding 4 principal components with a total variance contribution rate of 73.022%. In this study, through principal component analysis, the 11 indicators were simplified into 4 representative indicators, and 4 principal components were obtained, with a cumulative variance contribution rate of 73.022%. The 11 evaluation indicators were comprehensively evaluated using the mean value of the affiliation function and the D-value of the comprehensive evaluation and found that the HD198 having the highest drought resistance and the HD304 having the lowest drought resistance.

Zhang et al. (2018) evaluated the drought resistance of 10 new hybrid indica rice combinations using the pot test and screened out three comprehensive indicators of drought resistance, which include the number of effective panicles, the solid grain weight of a single panicle, and the seed setting rate. Lai et al. (2015) selected five traits (i.e., the number of tillers in a single plant, the plant's height, the density of grains, the number of effective panicles in a single plant, and the number of solid grains in a single panicle, among others) to be used as index traits for identifying drought resistance. Zhao Yan et al. (2021) used five traits such as yield, number of panicles, number of grains per panicle, 1000-grain weight, and plant height. In this study, we analyzed the correlation between comprehensive evaluation

D-value and the drought tolerance coefficient of rice. The correlation degree between each agronomic trait index and drought tolerance of rice was as follows: Filled grains per panicle> plant height > Grains per panicle> Seed setting rate > 1000 – grain weight > Effective panicle number > Grain width > Grain length > Grain length-width ratio > Panicle length > Grain yield per plant. There were also correlations between the agronomic shape indexes, which indicated that the comprehensive evaluation D value could better reflect the drought tolerance of hybrid rice, and it could be used to evaluate the hybrid rice. In this study, the coefficient of variation, stepwise regression analysis, and correlation screening results were combined to evaluate the drought tolerance of hybrid rice. The number of grains and plant height were used to identify the drought tolerance of rice materials under drought stress.

Research on quality evaluation of different hybrid rice combinations

Quality attributes emerge from genetic inheritance and interactions with the external environment; therefore, improving rice quality and selecting high-quality rice are key aspects of contemporary rice breeding research (Aznan et al., 2023). Rice quality is reduced in dry farming, which mainly reduces the appearance (increased chalky whiteness) (Liu et al., 2010) and processing quality (reduced whole semolina rate) (Rajjou et al., 2012; Vanstraelen et al., 2012). Whole brown rice rate and whole semolina rate are the main characteristics of processing quality (Zhou et al., 2015). Liao et al. (2021) showed that rice had the highest tasting score value at roughly 18.5% straight-chain starch contents and the highest tasting score value at about 6.5% protein content. In this study, 130 materials were tested for brown rice rate, refined rice rate, whole refined rice rate, straight-chain starch content, and other indicators to find the high-quality combinations for 50 rice hybrid combinations. The 50 hybrid combinations were classified into three categories through cluster analysis, which were strong drought-resistant, medium drought-resistant and drought-sensitive. The data of this experiment fully demonstrated that the water stress affects the change of the main quality indexes, which is in line with the previous research. The results of the study provide a reference basis for screening high-quality drought-resistant hybrid rice combinations. Further research is needed to examine the pattern of quality change of drought-resistant hybrid rice combinations.

CONCLUSIONS

Under drought stress, the agronomic and yield indicators of hybrid rice combinations exhibited substantial variations in drought resistance coefficient and changes in standard deviation, mean value, and coefficient of variation. Among them, the coefficient of variation in yield per plant was the highest (44.35%), while the coefficient of variation in grain length was the lowest (3.50%). The drought resistance coefficient of all indexes was analyzed by principal component analysis. Four principal components with eigenvalues greater than 1 were obtained, and the cumulative variance contribution rate was 73.022%. The eigenvalue of principal component 1 was 3.432, which was determined by total grain number, filled grain number, effective panicle, and plant height, and the contribution rate was as high as 31.197%. The drought resistance of 130 new hybrid rice combinations was comprehensively evaluated by the mean value of membership function and the comprehensive evaluation D value. The drought resistance of HD198 was the strongest, and that of HD304 was the weakest. The comprehensive evaluation D value was highly correlated with plant height, effective panicle, total grain number, filled grain number, seed setting rate, 1000 – grain weight, and grain width.

The quality indexes were evaluated, such as head rice rate and amylose content of 130 hybrid combinations. A total of 50 high-quality combinations were screened, of which 35 met the first-class rice standard, 11 were second-class rice, and 4 were third-class rice. Cluster analysis was carried out on 50 high-quality combinations, which were divided into strong drought-resistant type, medium drought-resistant type, and drought-sensitive type. Among the three drought-resistant types, a total of 7 hybrid rice combinations were strong drought-resistant first-grade rice and the material HD034 was strong drought-resistant second-grade rice. Material HD522 is drought-sensitive rice; the remaining materials were medium drought-resistant. Finally, the hybrid rice combinations with strong drought resistance and excellent rice quality were selected as materials HD009, HD024, HD171, HD207, HD432, HD447 and HD0451.In summary, this study revealed the differences in drought resistance of new rice hybrid combinations under drought conditions through quantitative analysis and comprehensive evaluation methods. At the same time, the quality of the combinations was graded, and the test materials were divided into different drought resistance types based on drought resistance and quality indicators, which provided a scientific basis for rice drought resistance breeding and variety breeding.

Acknowledgements

The research was supported by the Young Talent Project of Anhui Academy of Agricultural Sciences (QNYC-202109, QNYC-202208), Anhui Provincial Key Research and Development Program (2022h11020011,2023h11020007), Anhui Natural Science Foundation Project (2208085QC82), and Anhui Provincial Science and Technology Major Project (2021d06050002).

REFERENCES

1. Aznan, A., Gonzalez Viejo, C., Pang, A., Fuentes, S. 2023. Review of technology advances to assess rice quality traits and consumer perception. Food Research International, 172, 113105. https://doi.org/10.1016/j.foodres.2023.113105
2. Cordell, D., Drangert, J.-O., White, S. 2009. The story of phosphorus: Global food security and food for thought. Global Environmental Change, 19(2), 292–305. https://doi.org/10.1016/j.gloenvcha.2008.10.009
3. Hassan, M.A., Dahu, N., Hongning, T., Qian, Z., Yueming, Y., Yiru, L., Shimei, W. 2023. Drought stress in rice: morpho-physiological and molecular responses and marker-assisted breeding. Front Plant Sci., 18(14), 1215371. doi: 10.3389/fpls.2023.1215371. PMID: 37534289; PMCID: PMC10391551.
4. Hu, Y., Wang, Z., Huang, T., Chu, X., Li, J., Yuan, H. et Zhang, Y. 2006. Morphological evaluation indexes for the identification of drought tolerance in rice varieties. Journal of Southwest University of Science and Technology, 1, 102–108.
5. Jiang, H., Xing, X., Meng, X., Chen, J., Yu, K., Xu, X., Zhang, R., Wei, Z., Wang, D., Cang, B., Bai, C., Li, Y., Jiang, Z., Wei, X., Tian, P., Yang, M., Wu, Z. 2023. Research progress in water-saving cultivation of rice in China. Crop Science, 63(5), 2623–2635. https://doi.org/10.1002/csc2.21068
6. Lai, C., Zhang, W., Ma, J., Ying, Y. 2015. Research on drought resistance and comprehensive evaluation of rice in Ningxia. Jiangsu Agricultural Science, 43(8), 86–91. https://doi.org/10.15889/j.issn.1002-1302.2015.08.028
7. Li H., Huang Y., Chen C., Reziya A., Shen Y., Zhang T. 2023. Identification and evaluation of seedling drought resistance of yellow clover germplasm resources. China Grassland Journal, 45(10), 34–45. https://doi.org/10.16742/j.zgcdxb.20230011
8. Liao, M., Zhou, W., Zhu, Z., Tan, Y., Peng, D., Liu, W. et Tang, X. 2021. A preliminary study on the application of rice flavour meter in the selection of new combinations of excellent flavour hybrid rice. Hybrid Rice, 36(4), 11–17. https://doi.org/10.16267/j.cnki.1005-3956.20210204.050
9. Liu, D., Zhang, J., Cao, J., Wang, Z., Yu, C. et Jin, D. 2010. The reduction of amylose content in rice grain and decrease of Wx gene expression during endosperm development in response to drought stress. Journal of Food, Agriculture & Environment, 8(3/4 part 2), 873–878.
10. Lv, X., Bai, H., Hui, J., Tian, X., Yang, C., Ma, S., Cai, Z., Li, S. 2019. Evaluation of seedling drought tolerance in indica-japonica rice hybrid-derived RIL lines. Journal of Plant Genetic Resources, 20(3), 556–563. https://doi.org/10.13430/j.cnki.jpgr.20180817001
11. Mau, Y.S., Ndiwa, A.S., Oematan, S.S., Markus, J.E. 2019. Drought tolerance indices for selection of drought tolerant, high yielding upland rice genotypes. Australian Journal of Crop Science, 13(1), 170–178.
12. N'guessan, K.J.Y., Adahi, B., Konan-Waidhet, A., Masayoshi, S., Assidjo, N.E. 2023. Assessment of Climate Change Impact on Water Requirement and Rice Productivity. Rice Science, 30(4), 276–293. https://doi.org/10.1016/j.rsci.2023.03.010
13. Oladosu, Y., Rafii, M.Y., Samuel, C., Fatai, A., Magaji, U., Kareem, I., Kamarudin, Z.S., Muhammad, I., Kolapo, K. 2019. Drought Resistance in Rice from Conventional to Molecular Breeding: A Review. Int J Mol Sci., 20(14), 3519. doi: 10.3390/ijms20143519. PMID: 31323764; PMCID: PMC6678081.
14. Qin, L., Li, J., Du, Y., Zhang, J., Sun, H., Han, Y. et Zhao, Q. 2013. Screening of suitable dry rice varieties and identification indexes in wheat stubble rice area of Henan and Huaihe River. Agricultural Research in Arid Regions, 31(1), 161–165.
15. Rajjou, L., Duval, M., Gallardo, K., Catusse, J., Bally, J., Job, C., Job, D. 2012. Seed Germination and Vigor. Annual Review of Plant Biology, 63(1), 507–533. https://doi.org/10.1146/annurev-arplant-042811-105550
16. Khan, R.M.I., Palakolanu, S.R., Chopra, P., Rajurkar, A.B., Gupta, R., Iqbal, N., Maheshwari, C. 2021. Improving drought tolerance in rice: Ensuring food security through multi-dimensional approaches. Physiologia Plantarum, 172(2), 645–668. https://doi.org/10.1111/ppl.13223
17. Salgotra, R.K., Chauhan, B.S. 2023. Ecophysiological Responses of Rice (*Oryza sativa* L.) to Drought and High Temperature. Agronomy, 13(7), 1877.

https://doi.org/10.3390/agronomy13071877

18. Vanstraelen, M., Benková, E. 2012. Hormonal Interactions in the Regulation of Plant Development. Annual Review of Cell and Developmental Biology, 28(1), 463–487. https://doi.org/10.1146/annurev-cellbio-101011-155741
19. Wang, C., Zhou, L., Zhang, G., Zhang, L., Xu, Y., Gao, X., Jiang, Shao, M. 2017. Identification of drought resistance during germination and screening of drought resistance indexes in germplasm resources of Coix lacryma. Journal of Plant Genetic Resources, 18(5), 846–859. https://doi.org/10.13430/j.cnki.jpgr.2017.05.006
20. Wang, Y., Huang, J., Wang, J., Findlay, C. 2018. Mitigating rice production risks from drought through improving irrigation infrastructure and management in China. Australian Journal of Agricultural and Resource Economics, 62(1), 161–176. https://doi.org/10.1111/1467-8489.12241
21. Wang, Y., Lv, J., Zhang, J., Li, J., Wang, C., Ding, Z., Zhang, C., Yao, Y., Li, Z. 2005. Identification method and index of drought resistance of upland rice – identification of drought resistance during the whole growth period. Agricultural Research in Arid Regions, 4, 129–133.
22. Yang, J., Chen, X., Zhu, C., Peng, X., He, X., Fu, J., Ouyang, L., Bian, J., Hu, L., Sun, X., Xu, J., He, H. 2015. RNA-seq reveals differentially expressed genes of rice (*Oryza sativa*) spikelet in response to temperature interacting with nitrogen at meiosis stage. BMC Genomics, 16(1), 959. https://doi.org/10.1186/s12864-015-2141-9
23. Zhang, H., Zhu, C., Tan, J., Li, X., Yang, W., Kang, H. 2018. Research on identification evaluation and prediction of drought resistance of new hybrid indica rice combinations. Arid Region Agricultural Research, 36(2), 161–169.
24. Zhao, J., Zhou, W., Ren, J., Guo, P., Xu, Y. 2019. Comprehensive evaluation of drought resistance of 50 new wheat germplasm. Shanxi Agricultural Science, 47(11), 1895–1899.
25. Zhao, Y., Ma, Y., Jiang, F., Xu, J., Li, S. 2021. Comprehensive evaluation of drought resistance of wheat varieties (lines) at planting stage in the Huanghuai wheat region. Molecular Plant Breeding, 19(12), 4100–4107. https://doi.org/10.13271/j.mpb.019.004100
26. Zhou, L., Liang, S., Ponce, K., Marundon, S., Ye, G., Zhao, X. 2015. Factors affecting head rice yield and chalkiness in indica rice. Field Crops Research, 172, 1–10. https://doi.org/10.1016/j.fcr.2014.12.004