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Evaluation of Submergence Tolerance of Different Rice Genotypes at Seedling Emergence Stage under Water Direct Seeding

Xia Su[1], Hui Wu[1,2*], Jing Xiang[2*], Jingjing Zhan[1], Juqin Wang[1], Xiaomin Li[1], Yihao Wei[1], Haifang Dai[1*], Huizhe Chen[2]

[1]Faculty of Agriculture, Forest and Food Engineering, Yibin University, Yibin, China
[2]State Key Laboratory of Rice Biology, China National Rice Research Institute, Hangzhou, Zhejiang
Email: *wuhuiscience@163.com, *18958071661@163.com, *haifang0606@163.com

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Abstract

In this study, 60 direct seeding rice varieties with different genotypes were used as experimental materials. Through long-term submergence treatment (7 d and 14 d), the responses of different genotypes to submergence stress were compared in germination and seedling emergence, stem, leaf and root elongation, starch and other storage material consumption. The results showed that there were significant differences in submergence tolerance of different genotypes at the germination and seedling stage. Through further analysis by statistical methods such as correlation analysis, principal component analysis, weight comprehensive evaluation and cluster analysis, 60 varieties could be divided into four categories: strong submergence tolerance, medium submergence tolerance, weak submergence tolerance and submergence sensitivity, while 6, 22, 4 and 28 varieties were screened respectively. After 14 d and 4 cm deep submergence, more than 78.1% of rice seeds could germinate, and the average plant height and root length could reach more than 11.99 cm and 9.66 cm respectively. The dry matter mass, starch content and soluble sugar content per plant were significantly higher than those of other tolerant types. The average coleoptile of the sensitive type was only 3.17 cm, and the radicle had little elongation. The evaluation and variety screening of submergence tolerance of different genotypes of direct seeding rice at the seedling stage can provide a theoretical basis for further clarifying the mechanism of rice submergence tolerance, screening suitable direct seeding varieties and cultivating special varieties of direct seeding rice.

Subject Areas

Agricultural Science, Environmental Sciences

Keywords

Direct Seeding Rice, Emergence Stage, Submergence, Evaluation, Variety Selection

1. Introduction

Rice (*Oryza sativa* L.) is the main grain crop in China, and the sowing area accounts for one-third of the national grain crops. Direct seeding is one of the light and simplified cultivation modes widely used all over the world. In the wet direct seeding cultivation mode widely used in China, the primary problems of low yield and instability of direct seeding rice are poor seedling uniformity, low whole seedling rate and difficult weed control [1] [2] [3]. The construction of field water layer at the seedling emergence stage of direct seeding rice can have a good effect on field closure and grass control, but it often leads to long-term submergence of rice seeds. In addition, direct seeding rice has high requirements for rice field leveling, and the height difference is no more than 3 cm [1], which is often difficult to achieve in production, resulting in low-lying ponding in the field with different depths. At the same time, the emergence stage of direct seeding rice often meets a rainy environment. When rice seeds germinate, they are under submerged conditions, and the rates of stewed seeds, rotten seeds and dead seedlings are high, resulting in uneven emergence, uneven population structure, poorly high yield and yield stability. Therefore, direct seeding with water has higher requirements for the ability of submergence tolerance at the seedling emergence stage of different genotypes.

At present, the research on rice submergence treatment mainly focuses on the identification of submergence tolerance index, coleoptile elongation character, physiological mechanism of seed germination under hypoxia, and so on [4] [5] [6] [7]. Compared with normal germination, rice seeds only grow coleoptile and inhibit the growth of leaves and seed roots under a hypoxia environment such as submergence [8]. Strong submergence tolerant rice varieties rapidly elongate the coleoptile during submergence germination, so as to reach the aerobic environment in the upper layer of the water surface, provide an oxygen source for the growth of other organs such as roots and leaves and seed survival, and also provide necessary physiological and metabolic guarantee for the survival of rice [9] [10] [11] [12]. Moreover, in addition to survival rate and plant height, it is also necessary to comprehensively evaluate the waterlogging tolerance of different genotypes of direct seeding rice at the seedling stage in combination with factors such as root development, chlorophyll level and dry matter consumption.

At this stage, the planting of direct seeding rice in China basically and directly misappropriates the existing transplanted rice varieties, and there is no cultivation and application of special varieties for direct seeding rice. The existing rice varieties are numerous and disorderly. As direct seeding rice, it is difficult to ensure seedling emergence, seedling uniformity and stable yield due to uncertain submergence tolerance. Some high-yield and high-quality rice varieties cannot give full play to their yield and quality advantages under direct seeding mode. Therefore, it is one of the urgent problems to be solved in the current cultivation mode of direct seeding rice to further tap the potential of stable yield and yield increase under the direct seeding mode of existing rice varieties, improve the submergence tolerance and seedling rate of direct seeding rice, promote the full seedling and the whole seedling, and then build a reasonable population structure.

Through the methods of principal component analysis and cluster analysis, this study statistically analyzed and evaluated the response differences of 60 different genotypes of direct seeding rice varieties to submergence stress in terms of germination and seedling emergence, stem, leaf and root elongation, starch and other storage material consumption, which can provide a theoretical basis for further clarifying the mechanism of rice submergence tolerance, screening suitable direct seeding varieties and cultivating special varieties of direct seeding rice.

2. Materials and Methods

2.1. Experimental Design and Material Cultivation

The experiment was conducted in a university laboratory from 2020 to 2021. 60 different genotypes of rice were selected as the experimental materials (Table 1),

Table 1. List of tested varieties.

Serial number	Variety	Serial number	Variety	Serial number	Variety	Serial number	Variety
V1	Fyou498	V16	Yongyou1540	V31	Quanyou1606	V46	Huayou7978
V2	Yixiangyou2115	V17	Yongyou17	V32	Yixiang4245	V47	Chuanzhongyou107
V3	Chuanzhongyou3877	V18	Zhongzheyou8hao	V33	Chuanyou6203	V48	Jinlongyou548
V4	Dexiang4103	V19	Yongyou4953	V34	Quanyouyazhan	V49	Zhongjiazao17
V5	Gangyou827	V20	Zhaoyou5431	V35	Baixiangyou125	V50	Shendao2hao
V6	Jingliangyou534	V21	Taiyou390	V36	Jingyou8037	V51	Shendao47
V7	Chuankangyou6308	V22	Zhongxiangyou378	V37	Yongyou4949	V52	Shendao18
V8	Gangyou900	V23	Rongyou8329	V38	Shen9you28	V53	Dejing4hao
V9	Fuyou1hao	V24	Zhongxiangyou808	V39	Nei6you107	V54	Yanjing144
V10	De1you205	V25	Qianxiangyou626	V40	Yongyou4901	V55	Yanjing1813
V11	Deyou4727	V26	Huayou991	V41	Jinhuayou4907	V56	Yanjing1814
V12	Chuanzuoyou619	V27	Huayou790	V42	Chuanyou8723	V57	Rong7you523
V13	Yongyou7753	V28	Yongyou4911	V43	Nei5you39	V58	Quanyou607
V14	Yongyou538	V29	Shenliangyou534	V44	Chuanyou6245	V59	Zhangliangyou2018
V15	Yongyou6711	V30	Meixiangzhan2hao	V45	Zhongxiangyouzhuangmiao	V60	Cliangyouyuenongsimiao

which were provided by the crop institute of Sichuan Academy of Agricultural Sciences and the China Rice Research Institute of Chinese Academy of Agricultural Sciences. The sand is dried and screened and put into the cultivation box (inner diameter L × W × H: 100 mm × 100 mm × 90 mm), arrange the cultivation boxes neatly on the flat ground, and ensure that the sand depth of each box is 4 ± 0.5 cm through a ruler. The soil in the box is flat and 4 cm away from the box mouth, a total of 360 boxes.

Before the test, the sand shall be soaked by water spray. Each variety selects 100 plump grains/share, a total of 6. After soaking for 24 hours, evenly sow them on the wet sand surface, 100 grains per box, a total of 6 boxes for each variety. After sowing, water was injected along the edge of the box, and the submergence depth was 4 cm, so as to simulate the submergence environment of direct seeding rice at seedling stage.

The potted plants are placed in a light incubator at 25˚C, with a light cycle of 12 h/12 h. The water level is observed and replenished every day, so as to form a continuous submergence environment. After 0, 7 and 14 days of submergence treatment, samples were taken to detect relevant indicators.

2.2. Test Items and Methods

2.2.1. Emergence Rate

The germination number of rice seeds in each basin was counted and the seedling emergence rate (%) was calculated at 7 d and 14 d after submergence treatment. Each treatment had three replicates.

2.2.2. Plant Height and Root Length

At 7 and 14 days of submergence treatment respectively, 10 representative plants were selected from each box to keep the root system intact as far as possible, wash the root soil, and measure the plant height and root length of each plant respectively. If the root system is less than 1 mm, it is recorded as 0, that is, the radicle does not protrude. 10 strains per box, 3 boxes, 30 repetitions in total.

2.2.3. Plant Dry Matter Weight

At 0, 7 and 14 days of submergence treatment, 20 plants or rice seeds with the same growth were randomly selected/repeat, a total of 3 repetitions were put into small envelopes, dried to constant weight at 80˚C after killing at 105˚C and weighed (mg), and the dry matter mass of a single plant (mg) was calculated.

2.2.4. Plant Starch and Soluble Sugar Content

Plant dry matter was grinded into fine powder by high-flux grinder (Shanghai Jingxin). The concentration of starch and soluble sugar (%) was determined by anthrone concentrated sulfuric acid colorimetry, repeated three times. The content of starch and soluble sugar per plant and the total amount of non-structural carbohydrate (NSCs) (μg) were calculated according to the dry matter. The basic principle of the anthrone concentrated sulfuric acid colorimetry method: the furfural or carboxymethyl furfural formed by dehydration of the glucose group under the action of concentrated sulfuric acid reacts with anthrone, and the reaction is blue-green. Within a certain concentration range, the color depth is proportional to the glucose content [13].

2.3. Data Statistics and Analysis

Microsoft Excel 2016 software was used for data sorting and analysis; SPSS25.0 software for multivariate analysis such as principal component analysis and cluster analysis. The full name of SPSS is Statistical Product and Service Solutions, which means statistical products and service solutions. SPSS has always stood in the statistical software with its distinctive features, and is one of the most authoritative statistical software today. The basic functions of SPSS include data management, statistical analysis, chart analysis, output management, etc.; SPSS statistical analysis process includes descriptive statistics, mean comparison, general linear model, correlation analysis, regression analysis, cluster analysis, data simplification, multiple response and so on several categories. There are several statistical processes in each category. For example, regression analysis is divided into multiple statistical processes such as linear regression analysis, Logistic regression, Probit regression, weighted estimation, two-stage least squares method, and nonlinear regression. It also allows the user to select different methods and parameters [14]. For calculation of relevant indicators, refer to literature [15].

In order to eliminate the genotypic difference of each variety, the submergence tolerance coefficient of dry matter mass, starch, soluble sugar and non-structural carbohydrate per plant was converted, that is, the ratio of the measured value of 7 and 14 days to the measured value of 0 days.

Membership function values of comprehensive indexes of different rice varieties $u(X_j)$:

$$u\left(X_j\right)=\left(X_j-X_{\min}\right)\Big/\left(X_{\max}-X_{\min}\right),\quad j=1,2,\cdots,n \tag{1}$$

1) The weight of each comprehensive index w_j:

$$w_j=p_j\Big/\sum_{j=1}^{n}p_j,\quad j=1,2,\cdots,n \tag{2}$$

2) The comprehensive submergence tolerance of various rice varieties:

$$D=\sum_{j=1}^{n}\left[u\left(X_j\right)\times w_j\right],\quad j=1,2,\cdots,n \tag{3}$$

3) Among them, X_j represents the j^{th} comprehensive index; $X_{\min}$ represents the minimum value of the j^{th} comprehensive index; $X_{\max}$ represents the maximum value of the j^{th} comprehensive index. w_j represents the importance degree or weight of the j^{th} comprehensive index among all the comprehensive indexes; p_j represents the contribution rate of the j^{th} comprehensive index of the rice variety; D is the submergence tolerance of the rice variety evaluated by the comprehensive index under submerged conditions Comprehensive evaluation value.

3. Results and Analysis

3.1. Performance and Correlation Analysis of Individual Indexes of Direct Seeding Rice under Submergence Conditions at Seedling Stage

It can be seen from Table 2 that the germination rate (ER), plant height (PH), root length (RL), dry matter mass (DW), soluble sugar (SS), starch (SC) content and non-structural carbohydrate (NSCs) of different varieties of rice were significantly different after 7 d and 14 d submergence treatment. Compared with 0 d, DW, SS, SC, NSC and other indicators of the tested varieties were reduced to varying degrees, but the decline was significantly different and the change was complex, indicating that the waterlogging tolerance of each variety was significantly different under 7 d and 14 d waterlogging treatment. It was difficult to reasonably evaluate the waterlogging tolerance of rice only by comparing the performance of different individual indicators.

From the correlation coefficient matrix of each single indicator (Figure 1), it can be seen that there is a large or small correlation between each single indicator, which will lead to overlapping information provided by them. At the same time, each single index plays a different role in the waterlogging tolerance of rice, which indicates that the waterlogging tolerance of rice is a complex comprehensive performance, and the direct use of each single index cannot accurately and intuitively reflect the waterlogging tolerance of rice. Therefore, in order to make up for the deficiency of classification and evaluation of waterlogging tolerance of single index, it is necessary to further use other multivariate statistical methods for multiple analysis on this basis.

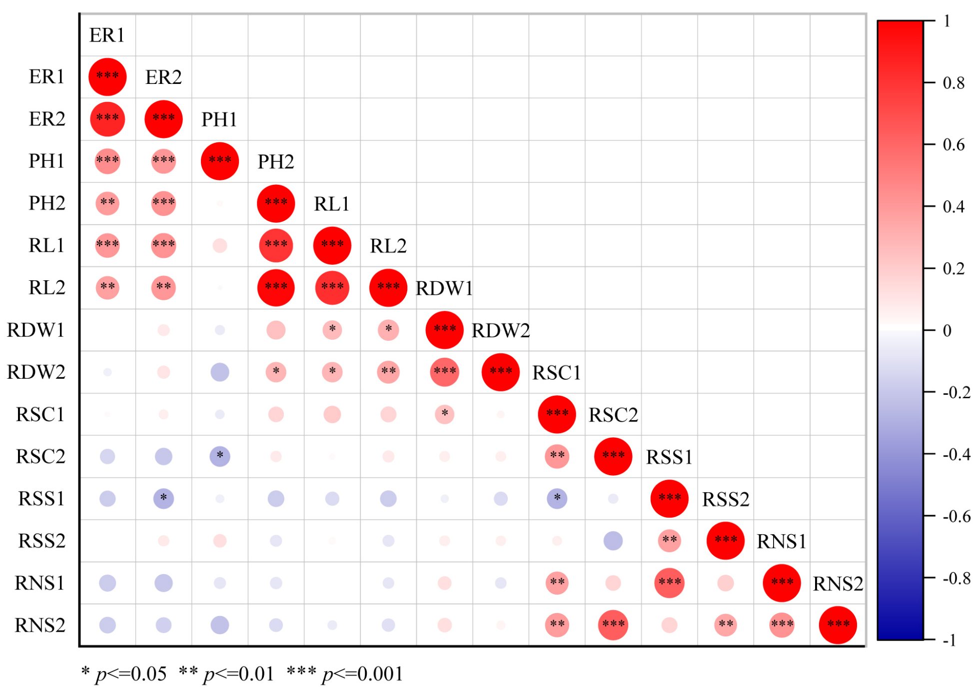

Figure 1. Correlation matrix of each single index of direct-seedling rice under submergence.

Table 2. The submergence tolerance performance of direct seeding rice in seedling stage under stress.

Variety	ER1	ER2	PH1	PH2	RL1	RL2	RDW1	RDW2	RSC1	RSC2	RSS1	RSS2	RNS1	RNS2
V1	54.5	65.0	2.38	2.91	0.39	0.69	85.9	79.7	36.5	30.4	640.0	344.3	0.978	0.668
V2	71.0	74.5	2.51	3.50	0.33	0.51	85.7	80.1	51.6	16.4	254.4	145.3	0.999	0.471
V3	42.5	46.5	1.96	2.96	0.00	0.00	87.1	71.8	74.5	51.8	1283.7	471.6	1.449	0.763
V4	76.5	50.5	3.32	3.62	0.10	0.25	87.3	66.9	82.2	50.9	735.9	790.4	1.131	0.858
V5	69.5	70.5	2.84	4.03	0.27	0.15	82.1	66.4	72.2	67.1	363.6	127.6	0.952	0.718
V6	79.0	82.0	3.13	3.56	0.48	0.62	89.4	79.6	75.2	45.1	34.5	24.2	0.610	0.378
V7	78.5	70.0	3.10	3.60	0.11	0.05	79.6	80.9	58.1	57.4	42.9	66.0	0.507	0.616
V8	32.5	31.5	1.62	3.76	0.00	0.00	85.3	75.5	84.3	29.2	85.8	176.4	0.847	0.688
V9	69.5	68.0	2.98	3.66	0.11	0.21	94.8	72.4	93.3	35.4	45.7	77.5	0.684	0.574
V10	26.0	28.5	1.08	2.71	0.00	0.00	89.1	84.5	86.2	78.9	84.9	80.1	0.859	0.791
V11	35.0	32.0	1.06	2.09	0.00	0.00	87.3	77.5	80.4	63.1	34.7	77.9	0.672	0.674
V12	36.0	47.5	1.05	7.59	0.63	4.50	94.5	91.7	80.8	75.0	220.6	179.6	0.943	0.850
V13	91.5	92.5	3.09	10.71	1.44	9.30	93.0	85.7	92.7	56.7	132.3	171.1	0.945	0.617
V14	78.5	81.0	2.67	3.25	0.77	0.86	91.5	76.7	74.1	48.6	102.7	79.4	0.767	0.514
V15	40.5	42.0	2.51	2.55	0.01	0.00	88.9	81.0	90.1	64.4	226.1	275.3	0.937	0.699
V16	41.5	46.0	1.38	5.15	0.05	1.06	86.6	79.1	55.9	50.1	171.8	99.5	0.598	0.518
V17	62.0	63.0	2.81	3.40	0.06	0.21	87.4	77.2	73.1	52.8	115.2	167.8	0.747	0.571
V18	70.0	73.0	2.91	3.44	0.04	0.65	93.7	82.8	83.2	53.3	483.5	397.6	1.054	0.724
V19	90.0	93.0	2.35	13.70	1.12	10.71	95.7	81.4	67.3	46.1	382.8	320.9	0.835	0.602
V20	69.5	80.0	2.47	8.62	0.62	6.07	98.2	90.5	93.2	68.5	134.4	104.3	0.983	0.728
V21	68.0	70.5	2.21	5.20	0.11	1.95	98.6	86.3	47.8	45.1	68.3	82.5	0.503	0.497
V22	52.0	58.5	1.75	2.24	0.00	0.00	92.1	82.7	64.2	55.4	384.4	215.5	0.911	0.688
V23	47.5	51.0	2.34	2.57	0.00	0.00	98.1	87.2	82.4	58.5	303.1	90.0	1.074	0.621
V24	47.0	50.5	2.13	1.95	0.12	0.10	90.8	86.3	84.8	79.5	396.8	78.1	1.068	0.794
V25	40.5	46.0	2.22	8.26	0.67	6.29	97.1	95.0	72.5	57.1	14.4	19.0	0.612	0.496
V26	57.0	64.5	2.69	3.45	0.16	0.09	92.3	91.6	37.0	9.7	340.3	1515.5	0.465	0.570
V27	41.5	45.0	2.55	3.02	0.67	0.47	97.4	83.3	67.6	17.5	152.7	249.3	0.774	0.444
V28	82.5	85.5	2.45	13.93	1.18	9.67	91.5	82.6	71.9	63.0	78.4	70.5	0.726	0.639
V29	34.0	35.5	2.31	9.84	1.13	7.95	99.2	86.0	89.5	70.9	460.5	978.1	1.047	1.082
V30	67.0	74.0	1.57	10.17	1.38	8.36	97.7	89.9	97.0	58.9	154.8	147.9	1.044	0.703
V31	79.5	77.0	3.25	5.59	0.95	1.65	95.0	89.1	72.4	13.4	223.8	325.4	0.838	0.368
V32	66.0	57.0	2.55	3.07	0.08	0.00	98.2	86.4	68.7	55.2	147.7	250.9	0.753	0.715
V33	71.0	65.5	1.49	2.64	0.00	0.06	98.2	84.9	90.4	59.1	172.9	189.3	0.938	0.646

Continued

V34	75.5	76.0	2.19	5.23	0.23	1.98	97.5	85.3	91.3	67.0	112.8	168.6	0.934	0.769
V35	76.0	70.5	2.01	2.37	0.24	0.12	95.1	78.6	36.5	70.8	304.1	214.6	0.551	0.807
V36	52.0	64.0	1.86	3.11	0.11	0.73	99.9	85.0	85.1	34.7	206.9	510.9	0.970	0.813
V37	87.0	88.0	2.30	13.58	0.73	11.99	97.5	87.1	57.0	21.3	130.6	92.5	0.643	0.284
V38	75.5	75.5	2.35	2.92	0.28	0.41	96.1	89.1	88.5	66.7	166.0	385.6	1.008	1.173
V39	58.0	60.5	2.83	3.08	0.01	0.10	96.5	84.7	80.7	68.4	106.0	206.6	0.838	0.853
V40	70.0	83.0	2.64	7.28	0.65	4.36	91.0	80.0	72.1	52.5	436.7	861.7	0.783	0.662
V41	65.5	76.0	2.46	3.41	0.20	0.54	98.8	86.4	84.4	25.9	515.2	725.8	0.967	0.459
V42	82.0	81.5	2.07	7.26	0.63	4.95	95.6	89.4	74.8	52.9	265.7	516.7	0.881	0.852
V43	53.5	79.5	2.62	3.84	0.05	0.53	97.0	84.8	72.2	45.9	154.1	392.3	0.831	0.920
V44	68.0	81.5	1.99	2.66	0.00	0.77	89.6	81.5	75.8	20.2	143.7	344.5	0.821	0.504
V45	57.0	73.5	2.08	2.76	0.12	0.28	92.6	87.7	87.7	49.9	350.1	968.5	1.013	0.976
V46	82.0	86.5	2.42	8.92	0.50	7.51	95.8	89.6	77.2	38.5	120.6	163.3	0.801	0.469
V47	64.0	81.0	2.60	3.26	0.53	0.29	91.6	81.5	94.9	32.8	370.2	1660.4	1.037	0.845
V48	63.5	72.5	2.22	5.94	0.51	2.19	94.0	81.1	99.1	38.1	290.9	589.9	1.133	0.791
V49	74.5	60.5	2.03	3.41	0.44	0.76	94.1	87.2	19.4	22.7	919.8	303.2	0.982	0.472
V50	60.0	53.0	2.23	2.82	0.48	0.31	93.3	80.6	85.2	50.5	322.2	307.8	1.137	0.815
V51	53.5	55.0	2.21	6.77	0.48	2.90	94.8	87.2	98.6	64.9	506.6	181.3	1.346	0.751
V52	68.5	50.5	1.86	5.08	0.05	2.09	81.5	83.7	48.3	44.3	376.4	256.5	0.737	0.607
V53	65.0	51.0	2.46	4.29	0.55	2.42	94.3	81.4	70.3	52.6	347.3	300.6	0.855	0.662
V54	63.5	44.0	2.26	5.72	0.31	2.93	97.7	76.7	98.3	42.2	278.3	306.1	1.084	0.571
V55	38.5	24.0	1.69	3.12	0.17	0.22	99.3	88.2	57.6	63.8	1457.7	606.4	1.294	0.916
V56	39.0	38.5	2.44	2.04	0.02	0.09	97.1	83.5	74.1	44.7	161.3	225.6	0.847	0.667
V57	30.5	47.0	2.73	3.15	0.01	0.15	90.3	82.7	35.5	11.5	644.4	155.3	0.914	0.246
V58	26.0	46.0	2.51	2.84	0.00	0.01	95.8	84.8	39.5	58.6	398.4	142.5	0.924	0.710
V59	56.5	53.5	2.79	3.30	0.00	0.00	89.6	73.0	34.6	28.4	336.7	135.0	1.031	0.525
V60	46.5	60.5	2.43	7.95	0.51	4.76	96.7	84.7	95.3	62.6	75.5	71.4	0.895	0.652

ER is germination rate, PH is plant height, RL is root length, RDW is relative dry matter, RSC is relative starch content, RSS is relative soluble sugar content; RNS is relative NSCs content; suffix 1 and 2 represented 7 d and 14 d submergence treatments, respectively.

3.2. Principal Component Analysis

Principal component analysis was performed on 14 individual indicators. The contribution rates of the first six comprehensive indicators CI_1 - CI_6 were 27.300%, 19.027%, 12.935%, 10.596%, 8.524% and 5.764%, respectively (Table 3). The cumulative contribution rate was 84.146%, which can be ignored. This

Table 3. Coefficients of comprehensive indexes and proportion.

Principle factors		CI_1	CI_2	CI_3	CI_4	CI_5	CI_6
Eigen values		3.822	2.664	1.811	1.483	1.193	0.807
Contributive ratio		27.300	19.027	12.935	10.596	8.524	5.764
Cumulative contributive ration		27.300	46.326	59.261	69.858	78.382	84.146
Eigen vector	ER1	0.676	−0.330	0.334	0.310	0.075	−0.062
	ER2	0.733	−0.283	0.306	0.230	0.235	−0.079
	PH1	0.257	−0.478	0.463	0.269	0.159	0.264
	PH2	0.861	0.224	−0.044	−0.104	−0.349	−0.086
	RL1	0.817	0.229	0.142	−0.078	−0.245	−0.027
	RL2	0.867	0.264	−0.065	−0.140	−0.318	−0.074
	RDW1	0.337	0.484	−0.010	−0.376	0.454	0.375
	RDW2	0.367	0.391	−0.226	−0.543	0.423	−0.053
	RSC1	0.175	0.597	0.037	0.521	0.197	0.316
	RSC2	−0.063	0.663	−0.294	0.473	−0.114	−0.186
	RSS1	−0.407	0.167	0.623	−0.386	−0.395	−0.004
	RSS2	−0.091	0.144	0.700	−0.212	0.349	−0.404
	RNS1	−0.282	0.558	0.542	0.012	−0.279	0.387
	RNS2	−0.254	0.729	0.233	0.318	0.178	−0.350

translates the original 14 individual indicators into 6 new independent composite indicators and represents the vast majority of information carried by the original individual indicators.

3.3. Comprehensive Indicators of Varieties

3.3.1. Analysis of Membership Function

According to Formula (1), the membership function values of each comprehensive index of rice varieties were calculated (Table 4). For the same comprehensive index such as CI_1, under waterlogging stress, the $\mu(X_1)$ value of Yanjing 1814 was the smallest, indicating that it showed the worst waterlogging tolerance in CI_1. The $\mu(X_1)$ of Yongyou 4953 was the largest, indicating that it had the strongest waterlogging tolerance in CI_1.

3.3.2. Weight Determination

According to the contribution rate of each comprehensive index, the weight can be calculated by Formula (2). After calculation, the weights of the six comprehensive index values are 0.324, 0.226, 0.154, 0.126, 0.101 and 0.068, respectively.

3.3.3. Comprehensive Evaluation

Formula (3) was used to calculate the comprehensive waterlogging tolerance of

Table 4. The value of each variety's $\mu(X_j)$, value D and comprehensive valuation.

Variety	$\mu(X_1)$	$\mu(X_2)$	$\mu(X_3)$	$\mu(X_4)$	$\mu(X_5)$	$\mu(X_6)$	D	Categories
V13	0.875	0.955	0.732	0.412	0.627	0.177	0.740	Strong
V19	1.020	0.719	0.514	0.404	0.542	0.342	0.702	Strong
V28	1.000	0.629	0.658	0.229	0.433	0.233	0.656	Strong
V29	0.714	0.273	0.850	0.560	0.787	0.618	0.617	Strong
V30	0.858	0.470	0.761	0.427	0.847	0.186	0.654	Strong
V37	0.922	0.677	0.211	0.256	0.787	0.126	0.605	Strong
V4	0.163	0.923	0.749	0.711	0.201	0.449	0.517	Medium
V5	0.277	0.785	0.780	0.436	0.000	0.193	0.455	Medium
V6	0.206	0.962	0.526	0.183	0.540	0.058	0.447	Medium
V9	0.041	0.970	0.662	0.307	0.627	0.000	0.437	Medium
V14	0.292	0.882	0.607	0.287	0.514	0.119	0.484	Medium
V18	0.136	0.845	0.695	0.505	0.692	0.309	0.497	Medium
V20	0.548	0.680	0.813	0.354	0.882	0.175	0.602	Medium
V31	0.336	1.000	0.301	0.424	0.926	0.172	0.540	Medium
V34	0.267	0.710	0.851	0.287	0.796	0.228	0.511	Medium
V38	0.164	0.711	1.000	0.260	0.795	0.554	0.519	Medium
V40	0.522	0.741	0.583	0.338	0.485	0.593	0.559	Medium
V41	0.123	0.837	0.422	0.516	1.000	0.350	0.484	Medium
V42	0.544	0.631	0.692	0.264	0.749	0.555	0.572	Medium
V45	0.133	0.619	0.788	0.333	0.759	0.731	0.473	Medium
V46	0.590	0.753	0.486	0.271	0.837	0.183	0.568	Medium
V47	0.170	0.922	0.701	0.441	0.700	0.912	0.560	Medium
V48	0.322	0.763	0.748	0.529	0.722	0.348	0.556	Medium
V50	0.200	0.618	0.751	0.533	0.657	0.244	0.470	Medium
V51	0.410	0.528	0.806	0.701	0.786	0.121	0.553	Medium
V53	0.328	0.577	0.587	0.403	0.636	0.257	0.460	Medium
V60	0.425	0.549	0.760	0.369	0.807	0.036	0.509	Medium
V54	0.265	0.679	0.667	0.608	0.762	0.014	0.497	Medium
V3	0.256	0.411	0.589	1.000	0.275	0.329	0.443	Weak
V12	0.572	0.019	0.776	0.286	0.762	0.322	0.444	Weak
V25	0.531	0.264	0.488	0.163	0.963	0.088	0.431	Weak
V55	0.291	0.076	0.504	0.904	0.801	0.566	0.423	Weak
V1	0.310	0.506	0.317	0.492	0.367	0.439	0.393	Sensitive

Continued

V2	0.247	0.762	0.317	0.428	0.470	0.190	0.416	Sensitive
V7	0.209	0.735	0.589	0.000	0.185	0.314	0.365	Sensitive
V8	0.117	0.297	0.590	0.336	0.431	0.119	0.290	Sensitive
V10	0.154	0.000	0.839	0.207	0.571	0.179	0.275	Sensitive
V11	0.137	0.098	0.714	0.133	0.418	0.153	0.246	Sensitive
V15	0.068	0.499	0.766	0.388	0.567	0.161	0.370	Sensitive
V16	0.304	0.156	0.446	0.133	0.382	0.212	0.272	Sensitive
V17	0.129	0.722	0.621	0.250	0.426	0.158	0.386	Sensitive
V21	0.251	0.544	0.386	0.058	0.827	0.236	0.371	Sensitive
V22	0.154	0.394	0.588	0.340	0.611	0.298	0.354	Sensitive
V23	0.054	0.541	0.661	0.487	0.937	0.057	0.402	Sensitive
V24	0.152	0.402	0.835	0.427	0.629	0.198	0.400	Sensitive
V26	0.122	0.604	0.109	0.077	0.845	1.000	0.357	Sensitive
V27	0.144	0.590	0.316	0.411	0.930	0.071	0.380	Sensitive
V32	0.084	0.630	0.631	0.226	0.856	0.282	0.401	Sensitive
V33	0.116	0.562	0.750	0.299	0.861	0.187	0.418	Sensitive
V35	0.249	0.477	0.598	0.069	0.455	0.504	0.370	Sensitive
V36	0.091	0.585	0.656	0.379	0.973	0.365	0.434	Sensitive
V39	0.053	0.677	0.826	0.254	0.779	0.260	0.426	Sensitive
V43	0.098	0.709	0.705	0.245	0.818	0.440	0.444	Sensitive
V44	0.125	0.743	0.453	0.261	0.648	0.272	0.395	Sensitive
V49	0.382	0.448	0.057	0.573	0.679	0.433	0.404	Sensitive
V52	0.388	0.319	0.408	0.207	0.268	0.419	0.343	Sensitive
V56	0.000	0.482	0.574	0.362	0.868	0.136	0.340	Sensitive
V57	0.125	0.461	0.000	0.593	0.688	0.066	0.294	Sensitive
V58	0.109	0.298	0.463	0.406	0.740	0.243	0.317	Sensitive
V59	0.138	0.648	0.313	0.527	0.415	0.123	0.356	Sensitive

each direct seeding rice variety (**Table 4**), and the waterlogging tolerance was sorted according to *D* value. Among them, the *D* value of Deyou 4727 is the smallest, indicating that its waterlogging tolerance is the worst; Yongyou 7753 had the highest *D* value, indicating its strongest waterlogging tolerance. Systematic cluster analysis of *D* value (**Figure 2**) can divide 60 varieties into four categories: six rice varieties such as Yongyou 7753 are the first category; zhaoyou 5431 and other 22 varieties belong to category 2; 4 varieties such as Chuanzhongyou 3877 belong to the third category; 28 varieties such as Deyou 4727 belong

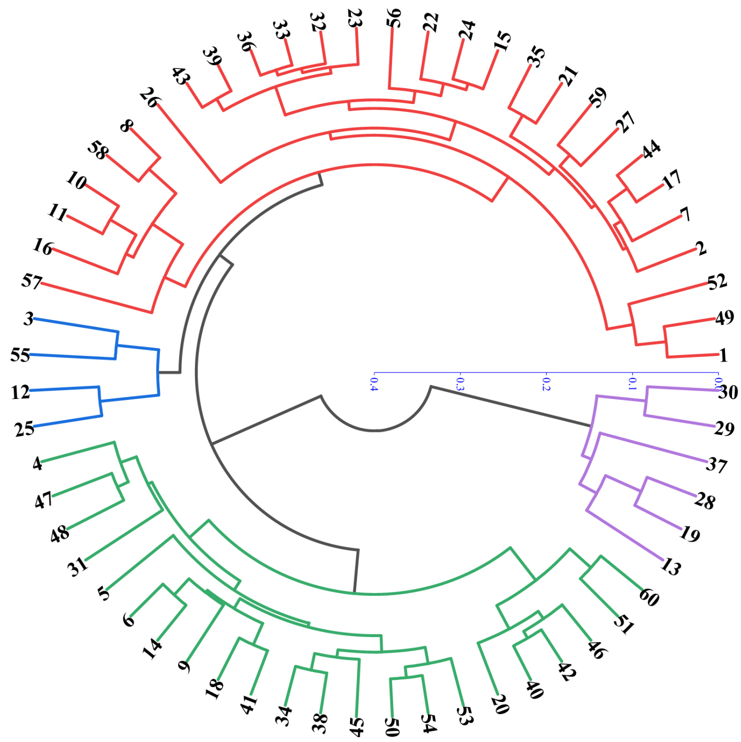

Figure 2. Cluster diagram of submergence tolerance of direct seeding rice of different genotypes at seedling emergence stage.

to the fourth category. Among them, according to the strength of submergence tolerance, the order is: Class 1 (Strong) > Class 2 (Medium) > Class 3 (Weak) > Class 4 (Sensitive).

4. Discussion

Compared with conventional seedling raising and transplanting, direct seedling cultivation of rice saves the process of raising seedlings and transplanting, and has the advantages of significant cost saving, labor saving, labor saving, seedling saving, high efficiency, and is conducive to mechanized operation [16] [17] [18] [19]. It has become the first choice for farmers who lack labor [20]. In addition, rice direct seeding also has significant advantages in saving water resources and reducing greenhouse gas emissions in rice fields [21]. It is an environment-friendly cultivation technology, which can solve the shortage of rural labor resources in the process of rice production and promote sustainable rice production. It plays an important role in increasing agricultural efficiency and farmers' income, and the development of direct seeding rice production is an objective need [22]. Despite this, the production of direct seeding rice still faces problems such as difficulty in cultivating the whole seedlings, serious weed damage, shortened growth period, insufficient utilization of temperature and light resources, easy lodging under shallow root system, and poor high and stable yield [1] [2] [3]. Periodic submergence leads to rotten seedlings and dead seedlings, and poor complete seedlings are the primary problems. Therefore, on the basis of existing rice varieties, screening of genotypes with strong submergence tolerance at the seedling stage can be directly applied to direct seeding rice production, and can also provide a basis for the breeding of special varieties of direct seeding rice and the promotion and control technology of direct seeding emergence.

Under the hypoxic conditions caused by long-term submergence, whether direct-seeded rice can quickly germinate and extend leaves out of the water surface is the basis for the survival of direct-seeded rice plants, as well as seedlings and whole seedlings. By investigating the emergence rate of plants, it can intuitively reflect the differences in waterlogging tolerance of different genotypes of direct seeding rice at the emergence stage. The stems, sheaths and leaves of submergence-tolerant rice will rapidly elongate in a submerged environment. By being exposed to oxygen outside the water, the supply of oxygen and the accumulation of carbohydrates can be maintained to improve plant survival. At the same time, the rapid elongation and development of the rice root system in the submerged environment is conducive to the upright rooting of seedlings. At the same time, the higher root volume forms a larger root surface area, which can promote the absorption of oxygen and nutrients underwater, but submergence often inhibits Radical development of rice seeds. Chlorophyll is an important medium for plants to absorb, transform and transmit light energy. Under adverse conditions, the reduction of photosynthetic function caused by changes in plant photosynthetic pigments often affects the accumulation of carbohydrates and even the survival of plants. Therefore, the level of chlorophyll content can be used to evaluate the potential of dry matter accumulation and plant survival.

Therefore, this study compared and analyzed the seedling emergence rate, stem and leaf elongation, root development and storage capacity of different genotypes of rice under direct seeding and submergence conditions. The results showed that more than 78.1% of the rice seeds of the strongly submergence-tolerant rice genotype could germinate after 14 days of submergence at a depth of 4 cm, and the average plant height and root length were over 11.99 cm and 9.66 cm, respectively. The quality, starch content and soluble sugar content were significantly higher than those of other submergence-tolerant types of direct-seeded rice, indicating that this type of rice has strong adaptability to long-term submergence environment, not only can survive a large proportion, but also has stronger adaptability to stress conditions; The submergence-sensitive rice genotypes were treated by long-term submergence, and only no more than 56.00% of the rice seeds could germinate. The average plant height and root length were only 3.17 cm and 0.38 cm, respectively, and there was almost no radicle protruding. It is not recommended to broadcast live broadcasts in areas with uneven terrain and rain, which may easily lead to production reduction and higher risks.

5. Conclusion

In this study, 60 rice varieties were compared and analyzed in terms of emergence, stem, leaf and root elongation, and storage material consumption under the condition of water direct seeding. Among them, 6 strong submergence-tolerant types and 22 medium submergence-tolerant types were screened. There were 4 rice genotypes with weak submergence tolerance and 28 submergence sensitive genotypes. The strong submergence tolerant rice genotypes could resist adversity through rapid elongation of stems, leaves and roots.

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Conflicts of Interest

The authors declare no conflicts of interest.

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