Drought Resistance Evaluation of Main Wheat Varieties in Shandong Province during Germination

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Abstract [**Objectives**] To identify the drought resistance of main wheat varieties in Shandong Province and screen suitable cultivars for dryland cultivation. [**Methods**] Employing eight varieties including Jimai 60 as test materials, this study simulated drought stress using 20% PEG-6000 and measured changes in germination-stage indicators. A comprehensive evaluation was conducted using the membership function method, incorporating relative coleoptile length, relative germ length, relative radicle length, relative germination rate, relative germination potential, and stress germination index. [**Results**] Drought stress not only reduced wheat seed germination rate but also inhibited the growth of the germ, coleoptile, and radicle. The D values of the eight varieties were ranked as follows: Jimai 60 > Linmai 9 > Yannong 999 > Shannong 30 > Shannong 28 > Luyuan 502 > Yannong 1212 > Jimai 22. Based on D values, the eight dominant wheat varieties were classified into three categories: highly drought-resistant varieties (Linmai 9 and Jimai 60), moderately drought-resistant varieties (Yannong 999 and Shannong 30), and sensitive varieties (the others). Linmai 9 and Jimai 60 are recommended as suitable wheat varieties for dryland cultivation in Shandong Province. [**Conclusions**] Drought stress induced by 20% PEG-6000 reduced germination rate, germination potential, and germination index of wheat varieties while inhibiting the growth of coleoptiles and radicles. These indicators can provide a preliminary assessment of drought resistance in wheat cultivars. However, since filter paper was selected as the growth medium, root length measurement errors were introduced during root washing, leading to variations in final experimental results. Futuer studies could attempt using sterilized sand as an alternative growth medium.

Key words Germination stage, Drought resistance, PEG-6000 stress, Membership function method, Comprehensive evaluation

0 Introduction

Shandong is a major wheat-producing province, with an annual wheat planting area of 4 million ha. However, the province also experiences water scarcity, possessing per capita water resources of less than one-sixth the national average[1]. This relative water shortage has severely constrained wheat production development in Shandong. In recent years, with global warming, natural disasters have exerted increasingly severe impacts on agricultural development. The drought-affected area in Shandong Province has accounted for over one-third of total agricultural land[2], making drought a primary factor limiting wheat yield improvement. Thus, screening and breeding drought-resistant wheat varieties is crucial for achieving high and stable wheat yields.

The germination stage represents a critical phase in wheat growth and development. Drought reduces seed germination rates and compromises seedling quality. Studies demonstrate that wheat seed germination rates and seedling vigor significantly influence subsequent vegetative and reproductive growth, with drought resistance during germination and seedling stages directly determining wheat yield and quality[3–4]. Given the heightened environmental sensitivity of these developmental phases, screening for germination-stage drought-resistant varieties becomes particularly crucial. Previous research indicates that seed drought resistance can be assessed through stress coefficients of embryonic structures, including embryo length, lateral root number, and coleoptile length during germination[5–7]. However, reliance on single or limited indicators often proves insufficient for comprehensive drought-resistant variety screening. As a multi-index evaluation approach, the membership function method has been extensively applied in drought resistance assessments of millet, maize, cucumber, wheat, cotton, and other crops[8–11]. Nevertheless, systematic evaluation of germination-stage drought resistance among major wheat varieties in Shandong Province remains unreported. Therefore, this study employed 20% polyethylene glycol solution to simulate drought stress, enabling identification and comprehensive evaluation of drought resistance in Shandong's primary wheat varieties at germination stage. The findings establish a theoretical foundation for screening drought-resistant and stress-tolerant wheat cultivars in Shandong Province[12–14].

1 Materials and methods

1.1 Test varieties Eight main wheat varieties in Shandong Province were Yannong 1212, Jimai 60, Linmai 9, Shannong 28, Luyuan 502, Jimai 22, Shannong 30, and Yannong 999.

1.2 Experimental design The experiment was completed in August 2023 at the physiology laboratory of Linyi Academy of Agricultural Sciences. Following the methods of Jing Ruilian and Wu

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Qi[15-17], the trial employed petri dish germination with two treatments: 20%-PEG6000 solution and distilled water (control), replicated three times. First, all required containers and instruments were sterilized, with petri dishes and incubators wiped using alcohol and air-dried. Experimental seeds were then selected, eight wheat varieties of uniformly plump, high-quality seeds were disinfected with 10% sodium hypochlorite for 10 min. After disinfection, seeds were rinsed three times with distilled water, and excess moisture was blotted with filter paper. Two layers of filter paper were placed in each petri dish as a germination bed, with 50 seeds evenly arranged per dish. The treatment group received 10 mL of 20%-PEG6000 solution, while the control received 10 mL of distilled water. Petri dishes were placed in a lighted incubator set at 25 ℃ with photoperiodic lighting (16 h of light and 8 h of dark).

1.3 Measurement methods The germination count of wheat seeds was recorded daily (germination criterion: radicle length reaching half of the seed length). Germination potential was calculated on day 3, while germination rate and germination index were determined on day 7. For each treatment, 10 randomly sampled seedlings were measured for shoot, coleoptile, and radicle lengths.

$$\text{Germination index } (GI) = \sum \frac{Gt}{Dt} \quad (1)$$

where Dt denotes the germination days, and Gt means the number of germination of seeds corresponding to the number of germination days Dt.

$$\text{Reduction rate} = (\text{Control} - \text{Treatment})/\text{Control} \times 100 \quad (2)$$

The drought resistance coefficient of relative germination rate and relative coleoptile length is calculated using Equation (3)[18]:

The drought resistance coefficient of an indicator = Measured value under PEG stress/Reference value (3)

With reference to Wang Zan and Yu Guihai[19-20], germination drought resistance index and germination stress index can be calculated using Equations (4) and (5):

Germination drought resistance index ($GDRI$) = Germination index under drought stress / Reference germination index (4)

$$\text{Germination index} = (1.00) \times nd_2 + (0.75) \times nd_4 + (0.50) \times nd_6 + (0.25) \times nd_8 \quad (5)$$

where nd_2, nd_4, nd_6 and nd_8 are germination rates on day 2, day 4, day 6, and day 8, and 1.00, 0.75, 0.50, and 0.25 correspond to the drought resistance coefficient of germination days.

Germination stress index = Germination index under PEG stress / Reference germination index (6)

1.4 Data analysis and processing SPSS 19.0 was used to process and analyze the data. The weighted membership function method[21-22] was employed for the comprehensive evaluation of drought resistance. Firstly, the data are standardized according to the following Equation (7):

$$u(X_j) = \frac{X_{max} - X_j}{X_{max} - X_{min}} \quad (7)$$

where $i = 1, 2, 3 \cdots n$, and X_j are the value of j-th indicator, X_{max} and X_{min} are the maximum and minimum values of the j-th indicator. For indicators with negative correlation with resistance, the calculation should first use $u(X_j) = (X_{max} - X_j)/(X_{max} - X_{min})$. Then, we used Equation (8) to calculation the standard deviation coefficient (V_j); calculated the weight coefficient using Equation (9); calculated the comprehensive evaluation value (CEV) using Equation (10). The stronger the drought resistance is, the higher the comprehensive evaluation value is.

$$V_j = \frac{\sqrt{\sum_{i=1}^{m} (X_{ij} - X_{mean})^2}}{X_{mean}} \quad (8)$$

$$W_j = \frac{V_j}{\sum_{j=1}^{n} V_j} \quad (9)$$

$$CEV = \sum_{j=1}^{n} [u(X_j) \times W_j] \quad j = 1, 2, 3 \cdots n \quad (10)$$

2 Results and analysis

2.1 Effects of PEG6000 stress on seed vigor of different wheat varieties The germination rate shows the seed germination ability, germination potential shows the seed germination speed. Both germination rate and germination potential are important indicators of seed germination ability, reflecting the seed vigor level. According to Table 1, under PEG6000 stress, the germination potential, germination rate and germination index of eight wheat varieties all showed a certain degree of reduction, with significant differences in reduction rates among varieties. The variety with the smallest reduction rate in germination rate is Yannong 999 at 11.3%, followed by Shannong 30 and Jimai 60 at 12.6% and 13.4%, respectively. The variety with the largest reduction is Yannong 1212 at 20.4%; the variety with the lowest reduction rate in germination potential is Yannong 1212 at 20.6%, while the highest is Shannong 28 at 37.9%; the variety with the lowest reduction rate in germination index is Luyuan 502 at 15.3%, and the highest is Jimai 22 at 25.5%. It can be seen that the reduction trends are not completely consistent among different varieties. The varying degrees of reduction in germination rate, germination potential and germination index indicate differences in drought resistance among wheat varieties, where smaller reductions indicate stronger drought resistance in that variety.

2.2 Effects of PEG6000 stress on drought resistance coefficient of different wheat varieties Under PEG6000 stress, the relative values of the indicators for the eight wheat varieties all decreased to varying degrees, with varieties exhibiting higher relative values showing lower degrees of inhibition. Table 2 shows that the relative germ length of the eight varieties ranged from 0.43 to 0.63, with Linmai 9 and Jimai 60 being the highest and Luyuan 502 the lowest; relative coleoptile length ranged from 0.89 to 0.95, with Linmai 9 and Jimai 60 being the highest and Jimai 22 the lowest; relative radicle length ranged from 0.69 to 0.78, with Jimai 60 and Shannong 30 being the highest and Luyuan 502 the lowest; relative germination potential ranged from 0.62 to 0.79, with Yannong 1212, Linmai 9 and Luyuan 502 being the highest and 'Shandong 28' the lowest; relative germination rate ranged from 0.81 to 0.89, with Yannong 999 and Jimai 60 being the highest and Jimai 22 the lowest.

Table 1 Effects of drought stress on germination potential, germination rate and germination index of 8 wheat varieties

Test varieties	Germination rate//%		Reduction rate//%	Germination potential//%		Reduction rate//%	Germination index		Reduction rate//%
	CK	PEG		CK	PEG		CK	PEG	
Yannong 1212	98.0 ab	78.0 b	20.4	90.7 a	72.0 a	20.6	16.0 ab	12.7 abc	20.4
Jimai 60	99.3 a	86.0 ab	13.4	90.7 a	59.3 bc	34.6	16.0 ab	13.1 ab	18.3
Linmai 9	99.3 a	84.7 ab	14.8	95.3 a	72.0 a	24.5	16.4 ab	13.5 ab	17.5
Shannong 28	94.7 c	81.3 ab	14.1	88.0 a	54.7 c	37.9	15.5 ab	12.3 bc	20.8
Luyuan 502	99.3 a	84.3 ab	15.1	92.0 a	70.0 a	23.9	16.2 ab	13.8 a	15.3
Jimai 22	96.7 abc	78.0 b	19.3	90.7 a	60.0 bc	33.8	15.8 ab	11.8 c	25.5
Shannong 30	95.3 bc	83.3 ab	12.6	86.7 a	59.3 bc	31.5	15.4 b	12.7 abc	17.4
Yannong 999	100.0 a	88.7 a	11.3	98.0 a	68.7 ab	29.9	16.6 a	13.9 a	16.2

Table 2 Effects of PEG6000 stress on drought resistance coefficient of different wheat varieties

Test varieties	Relative germ length	Relative coleoptile length	Relative radicle length	Relative germination potential	Relative germination rate
Yannong 1212	0.59 a	0.90 a	0.66 ab	0.79 a	0.80 a
Jimai 60	0.61 a	0.94 a	0.78 a	0.65 ab	0.87 a
Linmai 9	0.63 a	0.95 a	0.68 ab	0.76 ab	0.85 a
Shannong 28	0.59 a	0.93 a	0.62 ab	0.62 b	0.86 a
Luyuan 502	0.43 b	0.92 a	0.59 b	0.76 ab	0.85 a
Jimai 22	0.53 a	0.89 a	0.71 ab	0.66 ab	0.81 a
Shannong 30	0.54 a	0.91 a	0.72 ab	0.68 ab	0.87 a
Yannong 999	0.60 a	0.92 a	0.67 ab	0.70 ab	0.89 a

2.3 Correlation between different drought-resistant indicators Table 3 shows that various germination characteristics of wheat seeds under PEG6000 stress exhibit correlations to varying degrees. The relative germination potential is negatively correlated with the relative germination rate, relative germ length, relative coleoptile length, and relative radicle length. The Stress germination index is negatively correlated with relative germ length and relative radicle length. All other indicators show positive correlations among themselves, though the degree of correlation differs. Correlations, varying in strength, exist among the relative values of the eight wheat varieties. However, these correlations overlap, meaning that directly evaluating wheat drought resistance using any single indicator is inaccurate and requires further analysis.

Table 3 Correlation of germination characteristics of wheat seeds under PEG6000 stress

Correlation	Relative germ length	Relative coleoptile length	Relative radicle length	Relative germination potential	Relative germination rate	Stress germination index
Relative germ length	1					
Relative coleoptile length	0.434	1				
Relative radicle length	0.459	0.06	1			
Relative germination potential	−0.157	−0.047	−0.369	1		
Relative germination rate	0.160	0.582	0.125	−0.388	1	
Stress germination index	−0.131	0.492	−0.193	0.374	0.655	1

2.4 Comprehensive evaluation of drought resistance of wheat varieties under PEG6000 stress Using six data points including relative germination potential and relative germination rate as evaluation indicators, the Membership function method was employed to comprehensively evaluate the germination drought resistance of eight wheat varieties. The results are shown in Table 4. The comprehensive evaluation values (D-values) of the tested varieties ranged from 0.237 to 0.771. Based on their drought resistance capability from strongest to weakest, the eight varieties ranked as follows: Jimai 60 > Linmai 9 > Yannong 999 > Shannong 30 > Shannong 28 > Luyuan 502 > Yannong 1212 > Jimai 22. The drought resistance of each wheat variety was classified based on the D-value: $D \geq 0.7$ indicates high drought resistance; $0.7 > D > 0.5$ indicates moderate drought resistance; $D < 0.5$ indicates non-drought resistance[23]. The highly drought-resistant varieties were Jimai 60 and Linmai 9. The moderately drought-resistant varieties were Yannong 999 and Shannong 30. The other varieties were classified as sensitive varieties.

Table 4 Effects of PEG6000 stress on the Membership function values of indicators of wheat varieties

Variety	Membership function value							Rank
	Relative germ length	Relative coleoptile length	Relative radicle length	Relative germination potential	Relative germination rate	Stress germination index	Comprehensive evaluation *D*	
Yannong 1212	0.065	0.049	0.090	0.133	0.000	0.051	0.387	7
Jimai 60	0.073	0.237	0.236	0.026	0.128	0.071	0.771	1
Linmai 9	0.082	0.281	0.107	0.103	0.104	0.079	0.756	2
Shannong 28	0.065	0.189	0.038	0.000	0.116	0.047	0.454	5
Luyuan 502	0.000	0.136	0.000	0.108	0.097	0.101	0.442	6
Jimai 22	0.042	0.000	0.144	0.031	0.020	0.000	0.237	8
Shannong 30	0.047	0.075	0.159	0.049	0.144	0.080	0.553	4
Yannong 999	0.071	0.139	0.100	0.061	0.167	0.092	0.630	3

3 Discussion

Many factors influence wheat drought resistance, including endogenous factors and external environmental factors[24-25]. Seed germination and seedling growth represent the initial stages of plant development, and their quality is crucial for the entire growth process of wheat. The seed germination rate, seedling growth status, and germination physiological processes not only affect subsequent growth stages but also influence plant population establishment and biomass yield. Seed germination is a complex physiological process, among which water is one of the key factors affecting it. Therefore, researching the drought resistance of different wheat varieties during the germination period holds significant importance for the cultivation of dryland crops. Multiple indicators during wheat germination can reflect the level of drought resistance, such as vitality indices like germination rate and germination potential; germination characteristics like relative radicle length and relative germ length; as well as indices like the germination drought resistance index. The values of germination indicators under drought stress can reflect differences in drought resistance among varieties. Since field planting is susceptible to various natural conditions and anthropogenic factors, this study employed PEG to simulate drought stress for a comprehensive evaluation of wheat seed germination.

Research has found that PEG stress reduced the germination rate and germination potential of wheat, inhibiting the growth of radicles, germ, and coleoptiles, which is consistent with previous studies[26-27]. Different from related research, this study varied in the selection of trait indicators. Zhang Jun *et al.*[28] found that after PEG stress, germination rate, coleoptile length, germ length, main radicle length, and storage material transport rate were all suppressed, with varying degrees of reduction among different varieties. Strong drought-resistant varieties Jinmai 47 and Xiaoyan 22 were selected using the membership function method. Chen Tianqing *et al.*[29] showed that under PEG stress, germination rate, root length, seedling dry weight, and root dry weight all decreased. Ten drought-tolerant materials, including Jieyan 970012 and Guimai 13, were selected through drought stress screening. While many wheat varieties have been studied under drought stress, this study focused on selecting major wheat cultivars from Shandong Province. Under 20%-PEG6000 stress, the vitality indices of the tested wheat varieties, such as germination rate, germination potential, and germination index, decreased to varying degrees, while the growth and development of germ and radicles were significantly inhibited. These indicators can identify the drought resistance of wheat varieties to a certain extent. The membership function method was employed to comprehensively evaluate the drought resistance of different wheat varieties during germination, avoiding the limitations of single indicators and the influence of environmental and anthropogenic factors on seed germination. However, because filter paper was chosen as the growth medium, the cleaning of the root system introduced some error in root length measurement, leading to variations in the final experimental results. To facilitate cleaning, subsequent studies could attempt using sterilized sand as the growth medium.

4 Conclusions

Under 20%-PEG6000 stress, the germination rate, germination potential, and germination index of wheat varieties decreased, and the growth of germ and radicles was inhibited. Among the eight tested wheat varieties, the comprehensive evaluation values for drought resistance of Linmai 9 and Jimai 60 were 0.771 and 0.776, respectively, both greater than 0.7, classifying them as highly drought-resistant varieties. The comprehensive evaluation values for Yannong 999 and Shannong 30 were 0.630 and 0.653, respectively, between 0.5 and 0.7, classifying them as moderately drought-resistant varieties. The other varieties were classified as sensitive varieties.

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