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Yield Characteristics of a New High-quality Disease-resistant Wheat Variety Chuanmai 618

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Abstract [**Objectives**] The paper was to analyze the yield characteristics of a new high-quality disease-resistant wheat variety Chuanmai 618. [**Methods**] The yield characteristics of Chuanmai 618 were analyzed using the AMMI model and GGE biplot based on data from a 2-year regional test and a 1-year production test. [**Results**] The analysis of the AMMI model for the 2-year regional test indicated that Chuanmai 618 had a moderate yield and good stability. During the production test, Chuanmai 618 had an average yield of 450.52 kg/666.7 m^2, an effective spike of 235 700 spike/666.7 m^2, a 1 000-seed weight of 47.93 g, and a kernel number per spike of 47.28. The AMMI analysis sequencing graph showed that the varieties were ranked in the following order: Zhongkemai 1816 > Chuanmai 618 > Shumai 1958 > Chuanyu 42 > Mianmai 367 > Xikemai 5518. According to the GE analysis, Chuanmai 618 had comparative advantages. [**Conclusions**] The new wheat variety Chuanmai 618 is a high-quality disease-resistant variety with good yield and stability.

Key words Chuanmai 618; High quality; Disease-resistant; AMMI model; High yield; Stability

1 Introduction

Wheat is a strategic crop due to its resistance to cold, drought, and barrenness, as well as its strong adaptability. It is also the most widely distributed food crop in the world[1]. These characteristics make it advantageous in coping with climate change and facing the threat of natural disasters. In Sichuan Province, wheat is the second largest grain crop in terms of sown area and total production, following only rice[2]. Sichuan wheat is grown in rain-fed agricultural areas with simple cultivation and management. It can make full use of temperature, light, water, and various geological conditions for grain production during the winter and spring seasons when the temperature is low, and can be interplanted with other crops to improve the replanting index of arable land and increase the total annual grain production, playing an important role in guaranteeing food security[3-4].

There are several methods for analyzing the yield and stability of varieties, with the AMMI model and GGE biplot method being considered the most ideal, and these methods are widely used for analyzing yield characteristics[5-20]. By combining ANOVA and principal component analysis, the AMMI model, which stands for additive main effects and multiplicative interaction, decomposes the effects of genotype and environment interaction into genotypic and environmental components, and can use biplot to analyze the interaction between varieties and the environment more reliably, in order to identify the varieties with better stable yield[6-8,10,12-16]. The GGE biplot, which stands for genotype main effects and genotype × environment interaction, evaluates both varietal main effects and varietal-environment interaction effects, providing an effective method for evaluating varieties, experimental sites, and ecological regionalization, and the results can be presented clearly and intuitively in a graphical format[17-20].

Chuanmai 618 (Chuanshenmai 20220005) is a new wheat variety selected and bred by the Crop Research Institute of Sichuan Academy of Agricultural Sciences. The selection process followed these steps: the female parent was 34756, a high-quality material provided by the Chengdu Institute of Biology of the Chinese Academy of Sciences, and the male parent was SW9262, a self-breeding line from the Crop Research Institute of Sichuan Academy of Agricultural Sciences; the resulting (34756/SW9262) F_1 was then used as the female parent, and the male parent was replaced with the disease-resistant material 20828 to create a three-cross combination; the lines were stabilized in 2016 after 8 years and 10 generations of selection and breeding using low-generation hybrid selection and high-generation family selection methods, combined with generation-adding techniques through summer seeding; yield evaluation and disease identification were conducted from 2017 to 2019, followed by participation in the 2-year regional test from 2020 to 2021, and finally, participation in the production test in 2022. In the 2-year provincial regional test, the average yield was 392.57 kg/666.7 m^2, which was a 4.19% increase over the control. Out of the 15 sites, 12 showed an increase in yield, representing 80% of the total sites. The traits of the variety were as follows: average whole growth period 176.5 d, plant height 88.57 cm, effective spike 235 700 spike/666.7 m^2, kernel number per spike 47.28, and 1 000-seed weight 52.03 g; the variety had moderate tillering ability, with the kernel number per

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spike in harmony with the 1 000-grain weight. In the 2020 regional test, Rongxian and Jingyan uniformly sent samples for quality analysis to the Ministry of Agriculture and Rural Affairs Grain and Product Quality Supervision and Testing Center (Harbin). The results showed a capacity of 798 g/L, crude protein content of 13.04%, wet gluten of 29.2%, falling number of 246 s, formation time of 3 min, and stabilization time of 3.3 min. These results meet the high-quality medium gluten wheat standard of Sichuan Province. The Sichuan Plant Protection Institute conducted an inoculation resistance appraisal from 2020 to 2022, which revealed that the variety had high resistance to stripe rust, moderate susceptibility to powdery mildew, and moderate susceptibility and moderate resistance to wheat scab. The wheat functional chip detection results indicate that Chuanmai 618 possesses several stripe rust resistance genes, including *Yr26*, *Yr29*, *Yr82*, *Yr78*, *QYrsn*, *nwafu-1BL*, *QYrqin. nwafu-2AL*, and *QYrqin. nwafu-2BL*. Additionally, it contains the powdery mildew resistance gene *Pm12*, as well as scab resistance QTLs QFhb. caas-3BL and QFhb. caas-5AL, and leaf rust resistance genes *Lr46*, *Lr37*, and *Lr67*. Most users are not familiar with the yield characteristics of Chuanmai 618, which hinders the full utilization of its advantages and avoidance of risks during development and application. To ensure production safety and promote the use of new varieties, this study analyzed the yield characteristics of Chuanmai 618 using the AMMI model and GGE biplot method. The results will provide a reference for the promotion and research of new varieties.

2 Materials and methods

2.1 Materials and data sources

2.1.1 Two-year regional test. In 2020, Chuanmai 618 participated in the first-year wheat regional test of Sichuan Province. It was placed in the fourth group, which consisted of 13 varieties and a control (Mianmai 367), making a total of 14 varieties. Out of the 8 experimental sites, 5 test varieties passed the test. In the second-year wheat regional test in 2021, these 5 varieties were placed in the third group with Mianmai 367 as the control, and there were 7 effective experimental sites. The data from 2-year regional test, including 7 experimental sites and 6 varieties, were analyzed. The pilots and varieties are presented in Table 1. The experiment followed a randomized block design with three replications and a plot area of 13.34 m^2. Field management adhered to local high-yielding cultivation methods, which included insect treatment but no disease control. Harvesting was done promptly after maturity.

Table 1 Experimental sites and varieties

Two-year regional test				One-year production test	
Symbol	Experimental site	Symbol	Variety	Experimental site	Variety
E_1	Leshan	V_1	Yumai No. 7	Shuangliu	Shumai 1958
E_2	Nanchong	V_2	Shumai 1925	Shehong	Zhongkemai 1816
E_3	Shuangliu	V_3	Chuanmai 618 (high quality)	Mianyang	Chuanyu 42
E_4	Shehong	V_4	Kechengmai 15	Neijiang	Xikemai 5518
E_5	Mianyang	V_5	Chuanmai 804	Nanbu	Chuanmai 618 (high quality)
E_6	Xindu	V_6	Mianmai 367 (CK)	Dazhou	Mianmai 367 (CK)
E_7	Guangyuan	–	–	Zhongjiang	–

2.1.2 Production test. Chuanmai 618 participated in the Sichuan provincial production test in 2022. It was placed in the first group, which consisted of 6 varieties (including control). The experimental sites and varieties are presented in Table 1. The experiment was conducted using the large-area comparison method at 7 experimental sites without replication. The plot covered an area of 133 – 200 m^2. The control variety was arranged in the middle of the same group's plot. The plot's total harvest was converted into the yield. Field management adhered to local high-yielding cultivation methods, which included insect treatment but no disease control. The plots were harvested in a prompt manner after maturity.

2.2 Analysis methods The data were analyzed using the DPS data processing system (version 19.50)[21] and Microsoft Excel 2010. The regional test was analyzed using a multi-year, multi-point AMMI model, while the production test was analyzed using an unreplicated AMMI model and GGE biplot.

3 Results and analysis

3.1 Regional test

3.1.1 AMMI model analysis. The ANOVA results (Table 2) revealed that the yield was extremely impacted by year (Y), variety (V), experimental site (E) and mutual interactions (V × E, V × Y, E × Y, V × E × Y). The sum-of-squares of experimental site accounted for the largest proportion (52.39%), followed by mutual interactions (30.04% in total), variety (4.43%) and year (4.40%). This indicated that the main factor influencing yield variation was the variation of experimental sites, followed by mutual interactions dominated by E × Y and V × E interactions. The linear regression analysis results showed that the regression of mutual interaction and experimental site reached a highly significant level, and that of variety did not reach a significant level. The sum-of-squares of the three accounted for 21.74% of V × E interactions, *i. e.*, explaining 24.61% of V × E interactions. The residuals accounted for 78.26%, indicating that the linear regression of the regional test data was a poor fit. The analysis results of the AMMI model showed that IPCA1, IPCA2, and IPCA3 reached an extremely significant level, while IPCA4 did not reach a significant level. The sum-of-squares of the four accounted for 49.78% and the residuals accounted for 50.22% of the total, suggesting that AMMI model had better fitting effect than linear regression model.

Table 2 Analysis results of AMMI model

Method	Source of variation	Degree of freedom	Sum of squares	Mean square	F	Percentage of the total sum of square // %	Percentage of V × E interaction sum of squares // %
Complex variance analysis	Total	251	497.98	1.98		100.00	
	Treatment	83	454.44	5.48	21.12**	91.26	
	Y	1	21.89	21.89	84.45**	4.40	
	V	5	22.05	4.41	17.01**	4.43	
	E	6	260.89	43.48	167.76**	52.39	
	V × E	30	44.63	1.49	5.74**	8.96	
	V × Y	5	3.30	0.66	2.55**	0.66	
	E × Y	6	63.03	10.51	40.53**	12.66	
	V × E × Y	30	38.64	1.29	4.97**	7.76	
	Error	168	43.54	0.26		8.74	
Linear regression analysis	Interaction	30	44.63	1.49	5.74**		100.00
	Joint regression	1	1.08	1.08	4.16**		2.42
	Variety regression	4	0.64	0.16	0.62		1.44
	Site regression	5	7.98	1.60	6.16**		17.88
	Residual	20	34.93	1.75	6.74**		78.26
AMMI model analysis	Interaction	30	44.63	1.49	5.74**		100.00
	IPCA1	10	12.12	1.21	4.67**		27.14
	IPCA2	8	5.98	0.75	2.88**		13.39
	IPCA3	6	3.36	0.56	2.16**		7.52
	IPCA4	4	0.77	0.19	0.74		1.72
	Residual	2	22.41	11.21			50.22

Note: ** indicates extremely significant difference at 0.01 level.

3.1.2 High yield and stability analysis of Chuanmai 618. The AMMI model analysis produced a biplot with yields of various varieties and locations on the horizontal axis and IPCA1 values on the vertical axis (Fig. 1). On the horizontal axis, the varieties had higher yields the farther they were from the center origin. On the vertical axis, the varieties had better stability the closer they were to the abscissa axis. As shown in Fig. 1, the order of yields was V_2 > V_1 > V_5 > V_3 > V_4 > V_6, and the stabilities of the participating varieties were V_2 > V_5 > V_3 > V_4 > V_1 > V_6. Combining the yield and stability, V_2 (Shumaii 1925), V_5 (Chuanmai 804) and V_3 (Chuanmai 618) had better performance in yield and stability.

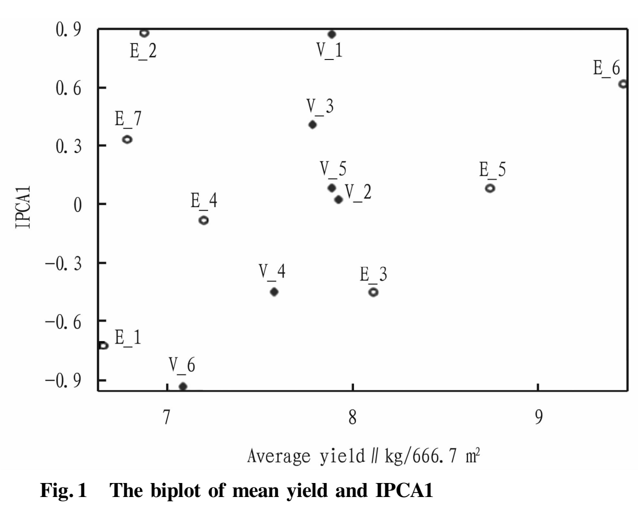

Fig. 1 The biplot of mean yield and IPCA1

Fig. 1 explains only 27.14% of the V × E interaction effects, while both IPCA1 and IPCA2 combined explain 40.53% of these effects. Therefore, a more accurate inference of varietal stability can be made by creating a biplot with IPCA1 as the horizontal axis and IPCA2 as the vertical axis (Fig. 2). In Fig. 2, the closer to the origin, the better the stability of the variety. Therefore, the stabilities of the varieties were successively V_3 > V_2 > V_4 > V_1 > V_6 > V_5, and the varieties V_3 (Chuanmai 618), V_2 (Shumai 1925) and V_4 (Kechengmai 15) showed better stability.

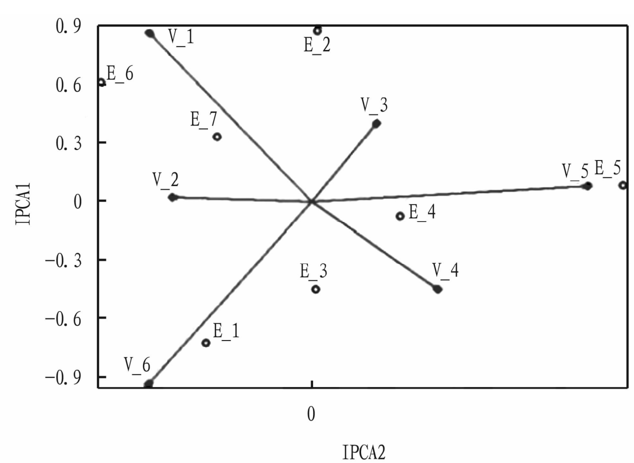

Fig. 2 The biplot of IPCA1 and IPCA2

Since IPCA1 and IPCA2 together explained 40.53% of the interaction effect, along with IPCA3 (7.52%) and IPCA4

(1.72%), the values of the stability parameter, $D_{g(e)}$, must be combined to determine the stability of the varieties[14]. The Euclidean distance of the variety or experimental site from the origin in the K-dimensional space of their relative stability parameter ICPA is represented by $D_{g(e)}$. A smaller value of $D_{g(e)}$ indicates a higher variety stability. As shown in Table 3, the $D_{g(e)}$ values of the participating varieties were successively V_1 > V_6 > V_5 > V_4 > V_3 > V_2, then the stabilities were successively V_2 > V_3 > V_4 > V_5 > V_6 > V_1. V_2 (Shumai 1925), V_3 (Chuanmai 618), and V_4 (Kechengmai 15) exhibited better stability.

Therefore, the analysis of the AMMI model and the stability parameter $D_{g(e)}$ for the two-year regional test indicated that Chuanmai 618 had moderate yield, good stability, and performed well in terms of high yield and stability.

Table 3 Stability parameters of varieties on interaction principal component axis

Symbol	Variety	Average yield kg/666.7 m²	Interaction principal components				$D_{g(e)}$ value	Rank
			IPCA1	IPCA2	IPCA3	IPCA4		
V_1	Yumai No. 7	394.5	0.87	−0.47	−0.52	0.11	1.123 5	1
V_2	Shumai 1925	396.5	0.02	−0.40	0.60	0.24	0.759 3	6
V_3	Chuanmai 618 (high quality)	389.0	0.41	0.19	0.37	−0.54	0.793 4	5
V_4	Kechengmai 15	378.5	−0.45	0.36	−0.53	−0.13	0.793 5	4
V_5	Chuanmai 804	394.5	0.08	0.80	0.13	0.35	0.885 4	3
V_6	Mianmai 367 (CK)	354.0	−0.94	−0.47	−0.04	−0.03	1.050 3	2

3.2 Production test The average yield of large-area production test in 2022 is shown in Table 4. The average yields were ranked as follows: Zhongkemai 1816 > Chuanmai 618 (high-quality) > Shumai 1958 > Chuanuu 42 > Mianmai 367(CK) > Xikemai 5518. Chuanmai 618 was ranked second, with a 3.33% increase in yield compared to the control. Yields increased at 6 out of 7 experimental sites, with a proportion of 85.71% in yield increase sites. In comparison, Chuanmai 618 had outstanding effective spikes, moderate 1 000-seed weight, and a small number of kernels per spike.

Table 4 Yield of large-area production test and average result of three factors

Variety	Yield kg/666.7 m²	Effective spike number ×10⁴/666.7 m²	1 000-seed weight//g	Kernel number per spike kernel/spike
Shumai 1958	450.08	23.14	44.74	51.06
Zhongkemai 1816	472.95	23.10	49.32	49.50
Chuanyu 42	444.34	21.79	46.69	52.96
Xikemai 5518	427.47	21.21	49.83	47.56
Chuanmai 618	450.52	23.57	47.93	47.28
Mianmai 367 (CK)	435.98	21.63	44.19	48.03

3.2.1 AMMI analysis sequencing graph. The unduplicated AMMI model in the DPS data processing system was used to analyze the production test data, and the AMMI analysis sequencing graph (Fig. 3) was plotted with the average yield of varieties on the horizontal axis and IPCA1 on the vertical axis. When a specific variety is indicated in the figure, two curves are plotted through that point. The characteristics of the variety can be analyzed by the point where the curves intersect. This means that the specified variety has superior characteristics compared to those falling to its left[21]. As shown in Fig. 3, the variety characteristics were successively Zhongkemai 1816 > Chuanmai 618 > Shumai 1958 > Chuanyu 42 > Mianmai 367 > Xikemai 5518, which was consistent with the order of yield. Chuanmai 618 ranked second with good variety characteristics.

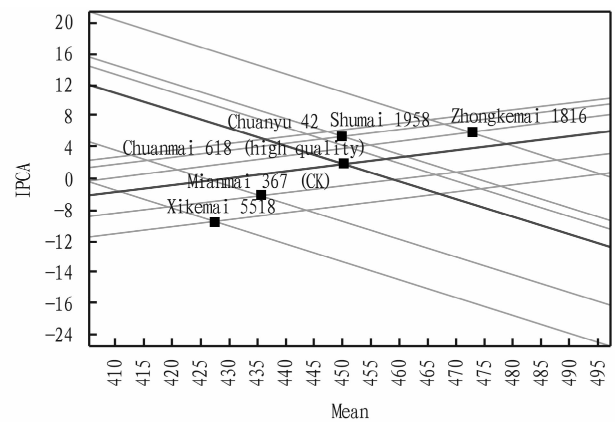

Fig. 3 AMMI analysis sequencing graph of varieties

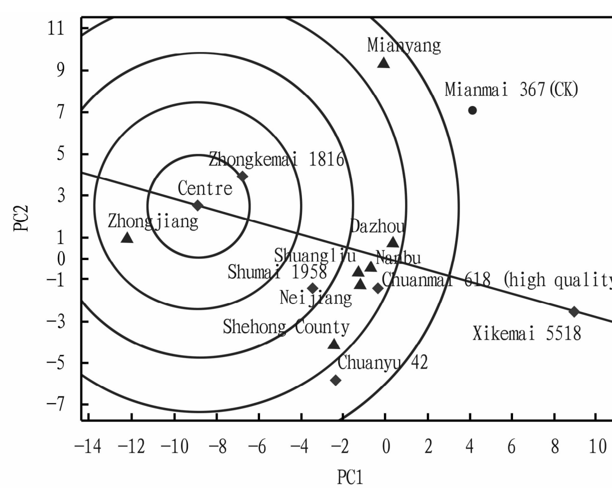

Fig. 4 GGE biplot with concentric circles of high and stable yield

3.2.2 GGE biplot analysis. The GGE biplot, available in the DPS data processing system, was utilized for analysis. The resulting GGE biplot displayed concentric circles indicating high and stable yield (Fig. 4). Varieties were judged based on their distance from the center point (also known as the ideal variety, a composite index of the average yield value and the average value of the environment, given equal weight), and the smaller the distance, the better the variety[21]. According to Fig. 4, Zhongkemai 1816 was the closest to the central point, followed by Shumai 1958; Chuanmai 618 was ranked No. 3 and was in the middle-upper level, with a comparative advantage in high yield and stability.

4 Discussion

Crop yield performance is affected by multiple factors such as variety, environment (abiotic and biotic environment), and cultivation management[22-31], posing a threat to production security. Crop regional tests and production tests are practical methods for evaluating the fertility, stability and adaptability of varieties, making great contributions to identifying good varieties, reducing risks and guaranteeing production safety, and these tests are an important process for varieties before they enter the market[6,12,15,17-20,32]. Analyzing data from regional and production tests can provide a wealth of information on variety characteristics, environmental effects, and interactions between varieties and the environment. This information can help users select the most suitable varieties and plan their production accordingly[33].

The yield characteristics of Chuanmai 618, a new high-quality medium-gluten wheat variety, were analyzed using various methods based on the data from regional and production tests. The ANOVA results indicated that yield was significantly impacted by year, variety, experimental site (*i. e.*, environment), and their mutual interaction. The variation in environment was found to be the main influencing factor leading to the variation in yield, followed by mutual interaction, and the effect of variety was relatively small, which is consistent with previous studies[13-16,19-20]. Controlling the year and its interactions is difficult due to the many uncertain factors involved. However, the effects of variety and variety-site (V×E) interactions are relatively controllable and provide valuable insights for breeding. The ANOVA results indicate that variety has a limited impact, while the interaction between varieties and experimental sites has a relatively large impact. Therefore, the study primarily analyzed the interaction between varieties and experimental sites. The biplots and calculation results of the stability parameter $D_{g(e)}$ in the AMMI model analysis revealed that Chuanmai 618, a new high-quality medium-gluten wheat variety, had a medium yield and good stability. In the 2-year provincial regional test, the average yield of 15 sites was 392.57 kg/666.7 m^2; in the regional production test, the average yield of 7 sites was 450.52 kg/666.7 m^2; and it had stable performance in yield during the regional tests among 3 years. AMMI analysis sequencing graph intuitively showed that Chuanmai 618 had better traits than Shumai 1958, Chuanyu 42, Mianmai 367 and Xikemai 5518. In the GGE biplot with concentric circles of high and stable yield, Chuanmai 618 was located in the same circle with several experimental sites, belonging to the upper-middle level, and had comparative advantages in high yield and stability.

5 Conclusions

After years of analysis and observation, it has been concluded that Chuanmai 618 has high 1 000-grain weight, full grain, bright white color, good quality, high resistance to stripe rust, and resistance to powdery mildew and scab. Its quality meets the standard of high-quality medium-gluten wheat. However, it has medium tillering ability, so the sowing amount should be increased appropriately. It is recommended to ensure the basic seedlings above 180 000 /666.7 m^2 in the plain and shallow hill areas to achieve high yield, stable yield and high quality. The study analyzed the yield characteristics of Chuanmai 618, a medium-gluten wheat variety, using the AMMI model and GGE double plot. The results indicate that Chuanmai 618 is a high-quality disease-resistant wheat variety with good and stable yield.

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