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Original Article

Water-Saving Evaluation of Jingmai Series Hybrid Wheat Varieties in China

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Abstract:
Wheat hybrids are recognized for their superior stress tolerance and stable yields, particularly excelling over conventional varieties under water stress conditions. This study evaluated two Jingmai series winter wheat hybrids across various ecological regions, employing three spring restricted irrigation regimes. The analysis focused on their population structure, leaf quality, and yield components in comparison to conventional wheat. Results indicated that the hybrids exhibited exceptional drought resistance and significantly higher yields under no spring irrigation (W0), with an average water-saving index of 1.514, demonstrating excellent water conservation capabilities. Yield variations were pronounced between single jointing irrigation (W1) and normal jointing plus flowering irrigation (W2). Under W0, hybrid wheat produced 13.9% and 15.8% more stems at the raising and jointing stages, respectively, and displayed significantly higher tiller ear-bearing rate across all three irrigation treatments. These findings confirm the hybrids' remarkable water-saving and drought-resistant characteristics; a high tiller ear-bearing rate is essential for water conservation and high yield, with ear number serving as a critical factor for achieving stable high yields. Implementing moderate irrigation to enhance tillering and heading can establish an optimal population, effectively balancing water conservation and high-yield production in hybrid wheat.
Keywords: hybrid wheat; water-saving; tiller ear-bearing rate; high yield

1. Introduction

Wheat, as one of the most essential food crops globally, plays a pivotal role in the landscape of food security and the advancement of agricultural economies in all nations. However, in the context of escalating global climate change, uneven water resource distribution, and the ongoing expansion of arable land in arid and semi-arid regions, water scarcity has become a fundamental constraint on increasing wheat yields [1].This issue is especially pronounced in the major wheat-producing regions of northern China, where the shortage of irrigation water during spring is particularly severe [2,3]. Consequently, achieving high and stable wheat yields under conditions of limited water resources has emerged as a critical research focus in agricultural science, necessitating urgent breakthroughs [4].

In recent years, crop scientists have systematically explored water-saving theories and developed related technologies aimed at enhancing wheat water use efficiency [5-7]. They have proposed a technical approach to achieving both water conservation and high yields by optimizing population structure, regulating cultivation practices, and maximizing the population advantages of wheat [8]. Furthermore, a series of supporting cultivation technologies, including late sowing with dense planting and precise water-fertilizer coupling, have been successfully developed, offering effective solutions for the water-efficient production of conventional wheat [9]. Simultaneously, empirical research has demonstrated that hybrid wheat, leveraging its exceptional stress tolerance and wide adaptability conferred by its genetic traits, excels in mitigating abiotic stresses such as drought and salinity [10]. Particularly in the realms of water conservation and stress resilience, it exhibits advantages that traditional wheat struggles to rival. Its capacity for high and consistent yields has been confirmed through trial cultivations across various regions, presenting a novel cultivar choice to mitigate the challenges of wheat cultivation in water-deficient regions [11-13].

Hybrid wheat exhibits a notable tillering advantage over conventional wheat, characterized by a greater number of lateral branches (tillers) emerging from the base of the main stem and enhanced growth vigor [14]. This trait theoretically contributes to yield improvement by increasing the number of effective panicles within the population [15]. However, current research primarily addresses the growth performance of hybrid wheat under optimal water and fertilizer conditions [16,17]. There remains a lack of comprehensive studies focused on regulating the tiller ear-bearing process and translating the tillering advantage into water-saving and high-yield capacity in water-limited environments. Additionally, there is a deficiency in reports detailing the relevant technical mechanisms and practical applications [18].

This study focuses on the Jingmai series hybrid wheat, which was independently developed by the Beijing Academy of Agricultural and Forestry Sciences. Comparative experiments are conducted across various ecological regions, using locally dominant conventional wheat varieties as controls. Three limited irrigation treatments are implemented. Systematic monitoring and comparison are performed to assess differences between hybrid and conventional wheat in terms of dynamic changes in population stems and tillers, leaf quality (specific leaf weight), and yield components (panicle number, grains per panicle, and 1000-kernel weight) [19,20]. The objective is to elucidate the response mechanisms of hybrid wheat to water stress [21], identify key technical aspects of its water-saving cultivation [22,23], and provide a scientific foundation and technical support for the accelerated adoption and application of hybrid wheat in arid and semi-arid regions, thereby contributing to the establishment of a water-saving and efficient wheat production system [24].

2. Materials and Methods

The varieties tested included Jingmai 6 and Jingmai 7, hybrid wheat cultivars independently developed by the Beijing Academy of Agricultural and Forestry Sciences. The control varieties consisted of conventional wheat cultivars Jingdong 17, Jingdong 12, and Lunxuan 987. The experiment was conducted at the Shunyi Comprehensive Experimental Station of the Hybrid Wheat Research Institute, Beijing, the Experimental Field of the Moyu County Seed Management Station in Hotan, Xinjiang, and the Experimental Field of the Agricultural Science Institute of the 4th Division of Yili, Xinjiang. All tested fields were established as long-term wheat variety comparison test sites, employing a double-cropping system that included winter wheat and summer corn each year.

The experimental design was predicated on the conventional water-saving cultivation model for wheat. Three water-saving irrigation treatments were established: no watering in spring (W0), one watering in spring (jointing water, W1), and two waterings in spring (jointing water plus flowering water, W2). This process was replicated four times, with each plot encompassing an area of 7.2 square meters (9 rows, row width 16 cm, length 5 m). The broadcasting period occurred from October 5 to 10. The sowing density adhered to the standards set by the National Unified Trial of Wheat Varieties in China.

At the flowering stage, 30 flag leaves, specifically the second and third leaves from the top, were selected from uniformly growing plants and subsequently mixed. A hole punch was employed to create holes in the center of the leaves while avoiding the main veins. The leaf samples were then placed in an oven at 105°C for 30 minutes to deactivate enzymes, followed by drying to a constant weight in an oven at 80°C for weighing, which was necessary to calculate the specific leaf weight [28]. The formula for this calculation is as follows:

Specific leaf weight (mg/cm^2) = Leaf weight / Leaf area

Following the emergence of wheat, four uniform sample segments, each measuring 0.2 m^2, were selected and fixed for each treatment. During critical growth periods—specifically the regreening, raising, jointing, and maturity stages—we examined the dynamic changes in population stems and tillers, and calculated the tiller ear-bearing rate [29-31]. The formula for this calculation is as follows:

Tiller ear-bearing rate (%) = (Panicle number at maturity stage - Basic seedlings) / (Total stem number at raising stage - Basic seedlings) × 100

Prior to wheat maturity, theoretical yield estimations were conducted for each combination, examining the panicle number per unit area, grains per panicle, and 1000-kernel weight. Each plot was harvested individually, followed by separate threshing, drying, and weighing to determine the yield and the percentage of yield increase or decrease. The water-saving index (WSI) was calculated based on the grain yield of the plot [32,33]. The calculation formula is as follows:

$$WSI = (Ya^4 / Ym) / (YA^4 / YM)$$

In the formula:

WSI — Water-saving index of the tested variety (line);

Ya — Yield of the tested variety (line) under water-saving treatment;

Ym — Yield of the tested variety (line) under normal irrigation;

YM — Yield of the control variety (line) under normal irrigation;

YA — Yield of the control variety (line) under water-saving treatment.

Here, Jingdong 17 was selected as the control variety. The experimental data were statistically analyzed using SPSS 11.5.

3. Results

The analysis of population structure (Table 1) revealed no significant difference in the total number of stems between hybrid and conventional wheat at the regreening stage. However, during the raising and jointing stages, the total stem number of hybrid wheat exceeded that of conventional wheat by 13.9% and 15.8%, respectively. Under the three irrigation methods—W2, W1, and W0—the ear numbers for hybrid wheat were $783 \times 10^4/hm^2$, $674 \times 10^4/hm^2$, and $584 \times 10^4/hm^2$, representing increases of 21.3%, 10.8%, and 7.9% over conventional wheat. Further comparisons indicated that the tiller ear-bearing rates for hybrid wheat were 14.8%, 22.6%, and 4.8%, which were also significantly higher than those of conventional wheat. These findings suggest that the notable tillering advantage and relatively high tiller ear-bearing rate are critical factors enabling hybrid wheat to achieve water savings and high yields under low-density planting conditions.

Table 1 Dynamics of plant population quantity in three irrigation treatments (×10^4/hm^2)

Varieties	Treatments		basic seedling	Growth Stages			
				Regreening	Raising	Jointing	Maturity
Jingmai 6	W0		356	651	1106	1076	561
	W1		330	521	1106	1065	671
	W2		305	630	1271	1140	765
Jingmai 7	W0		206	450	981	900	606
	W1		221	576	1080	866	675
	W2		225	761	1236	1050	801
Jingdong 12	W0		356	366	1076	885	600
	W1		266	606	1140	1005	666
	W2		300	846	990	926	701
Jingdong 17	W0		251	591	1056	810	510
	W1		285	645	1140	900	645
	W2		356	681	1155	996	666
Lunxuan 987	W0		351	600	861	716	591
	W1		366	566	840	761	621
	W2		356	795	930	896	675
Average	Hybrid Wheat	W0	281	551	1044	989	584
		W1	276	549	1094	966	674
		W2	266	696	1254	1095	783
	Conventional Wheat	W0	320	519	998	804	567
		W1	306	606	1040	888	644
		W2	338	774	1025	939	681

The examination of specific leaf weight for the top three leaves across various irrigation treatments (Table 2) revealed that as the irrigation amount decreased, the specific leaf weight of these leaves exhibited an increasing trend, indicating relatively higher leaf quality in hybrid wheat. Under the different irrigation treatments, hybrid wheat consistently demonstrated a higher specific leaf weight compared to conventional wheat. These findings suggest that the leaf quality of hybrid wheat surpasses that of conventional wheat, and that spring water-controlled irrigation practices are more effective in enhancing the leaf quality and increasing the specific leaf weight of hybrid wheat.

Table 2 Specific leaf weight of top leaf in different irrigation treatments (mg/cm^2)

Varieties		Treaments			Average
		W2	W1	W0	
Jingmai 6		3.60	3.75	4.00	3.80
Jingmai 7		3.60	3.85	4.20	3.90
Jingdong 12		2.90	3.30	3.55	3.25
Jingdong 17		3.35	3.60	4.25	3.75
Lunxuan 987		3.50	3.15	3.85	3.50
Average	Hybrid Wheat	3.60	3.80	4.10	3.83
	Conventional Wheat	3.25	3.35	3.88	3.49

Under the three irrigation methods—W0, W1, and W2 (Table 3)—the yield levels of hybrid wheat were 5469 kg/hm², 6918 kg/hm², and 7212 kg/hm², respectively, with no significant difference observed between W1 and W2. The average yield of hybrid wheat across the three irrigation methods was 6533 kg/hm², representing an 8.3% increase compared to conventional wheat. Notably, as the amount of irrigation decreased, the yield increase of hybrid wheat exhibited an upward trend, with increases of 0.3%, 4.1%, and 28.1% relative to conventional wheat, respectively. Particularly under conditions of no spring irrigation, the yield increase of hybrid wheat was substantial, and consistent results were obtained across multiple ecological planting areas. In conclusion, under spring-controlled irrigation conditions, the high-yield performance of hybrid wheat surpasses that of conventional wheat, and the influence of irrigation on hybrid wheat yield is less pronounced than on conventional wheat. This further underscores the water-saving and high-yield capabilities of hybrid wheat, as well as its robust resilience to environmental changes, indicating its suitability for promotion and application in arid and semi-arid regions.

The WSI serves as a crucial metric for assessing the water-saving performance of crop varieties. Research indicates that a WSI of 1.400 or higher signifies exceptionally strong water-saving capabilities. Experimental findings revealed that the average WSI for the two hybrid wheat varieties, Jingmai 6 and Jingmai 7, was 1.514, demonstrating their exceptional water-saving performance.

Table 3 Comparison of yield and WSI in different irrigation treatments

Sites	Varieties	WSI	Grain Yield (kg/hm^2)			
			W0	W1	W2	Avgerage
HeTian, Xinjiang	JingMai6	1.260	2287.5	5931.0	7075.5	5098.0
	JingMai7	1.434	4783.5	5997.0	6496.5	5759.0
	JingDong12	-	1786.5	5214.0	5428.5	4143.0
	JingDong17	-	2998.5	5355.0	5926.5	4760.0
	LunXuan987	-	3355.5	4284.0	5782.5	4474.0
YiLi, Xinjiang	JingMai6	1.840	7575.0	8290.5	8862.0	8242.5
	JingMai7	1.791	6861.0	8133.0	8433.0	7809.0
	JingDong12	-	6432.0	9579.0	10062.0	8691.0
	JingDong17	-	5574.0	7146.0	9004.5	7241.5
	LunXuan987	-	5289.0	9375.0	9609.0	8091.0
ShunYi, Beijing	JingMai6	1.596	5385.0	6798.0	6057.0	6080.0
	JingMai7	1.164	5920.5	6355.5	6348.0	6208.0
	JingDong12	-	5473.5	6478.5	6567.0	6173.0
	JingDong17	-	4567.5	6061.5	6112.5	5580.5
	LunXuan987		4689.0	6645.0	6682.5	6005.5
Avgerage	Hybrid Wheat	1.514	5469.0	6918.0	7212.0	6533.0
	Conventional Wheat	-	4270.5	6643.5	7189.5	6034.5

Correlation analysis (Table 4) revealed that under spring water-limited irrigation conditions, the yield of hybrid wheat exhibited a highly significant positive correlation with panicle number (r_1=0.883**). In contrast, the correlations with grains per panicle and 1000-kernel weight did not achieve significance (r_2=0.190, r_3=0.105). Path analysis indicated that the direct effects on hybrid wheat yield ranked as follows: panicle number (0.891) > grains per panicle (0.214) > 1000-kernel weight (0.010). Statistical analysis demonstrated that, under spring water-limited irrigation conditions, panicle number is the primary contributing factor for achieving stable and high yields of hybrid wheat. Furthermore, increases in grains per panicle and kernel weight may enhance the yield potential of hybrid wheat under spring controlled irrigation conditions.

Table 4 The correlation analysis of yield components and yield of hybrid wheat under water-saving condition

	Grain Yield	Panicle Number	Grains per Panicle	1000-Kernel Weight
Grain Yield				
Panicle Number	0.883**			
Grains per Panicle	0.190	-0.031		
1000-Kernel Weight	0.105	-0.272	0. 167	

4. Discussion

Numerous studies have investigated water-saving cultivation practices for conventional wheat [9,26]. Typically, high-density and large-population planting methods are employed to achieve both water conservation and high yields [8,17], with sowing densities often exceeding 500×10^4 plants/hm² and occasionally reaching 750×10^4plants/hm². Water-saving cultivation of conventional wheat emphasizes management strategies that are control-oriented during the spring [6,7]. However, if these measures are improperly implemented or poorly timed, high-density planting can result in an excessively large population. This situation may lead to issues such as suboptimal population quality and lodging in later growth stages, making it challenging to maintain a balanced yield component coordination [10,12]. Results from this experiment indicated that reducing the planting density of hybrid wheat by nearly half compared to conventional wheat, while maximizing the potential of individual tiller ear-bearing, can still satisfy the appropriate population criteria for water-saving cultivation. Furthermore, this approach optimizes individual quality and establishes a more balanced population structure, significantly mitigating the risk of lodging [14,21,22]. Investigating the mechanisms underlying the water-saving and drought-resistant advantages of hybrid wheat will enhance our understanding of wheat heterosis and expedite the production and application of hybrid wheat varieties [18,24].

The results of this experiment demonstrated that hybrid wheat exhibited significant water-saving and drought-resistant advantages under the three water-saving irrigation methods, W2, W1, and W0, when compared to conventional wheat [27,33]. The average water-saving index reached 1.514, indicating extremely strong water-saving performance, while the average yield increase across multiple sites was 8.3% [4,5]. This overall stable and high yield performance surpassed that of conventional wheat, aligning with previous research findings [13,16]. Regarding population structure establishment, hybrid wheat varieties such as Jingmai 6 and Jingmai 7 possess typical characteristics, including high tillering ability and a high tiller ear-bearing rate, which allow them to achieve an ideal population structure even under low planting density conditions, thus facilitating water-saving and high yield [29,30]. In terms of yield components, the primary contributor to the yield of hybrid wheat varieties like Jingmai 6 and Jingmai 7 is the number of panicles, which serves as the core foundation for achieving both water-saving and high yield [15,32]. Therefore, to maximize the water-saving and drought-resistant advantages of hybrid wheat, it is advisable to reduce the sowing density appropriately [23,25].

5. Conclusions

The results of this experiment indicate that, under conditions of spring water-limited irrigation, the number of panicles is the most significant contributor to the yield of hybrid wheat, while the contributions of grains per panicle and 1000-kernel weight are comparatively minor. The number of panicles serves as the primary factor for achieving stable and high yields in hybrid wheat. The reduction in sowing density optimizes the population structure of hybrid wheat, enhances the conditions for panicle differentiation, and facilitates the formation of larger panicles with a greater number of grains. Given the notable advantage of hybrid wheat's high tillering ability, research focused on key technologies to improve seed setting rates and kernel weight will further enhance yield levels under water-saving cultivation conditions.

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