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CULTIVAR RELEASE

Hehongzhan 2: a red rice variety for South China with blast and brown planthopper resistance

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Abstract: *Hehongzhan 2 is a new thermosensitive indica red rice variety with high yielding potential. It exhibits a moderately compact plant-type, moderate tillering capacity, and notable traits such as high blast resistance and moderate resistance to brown planthopper. This variety was developed in Guangdong, China.*

Keywords: *Red rice, breeding, brown planthopper-resistance gene, blast resistance, cultivation methods*

INTRODUCTION

With China's economic development and rising living standards, public food demands have shifted from basic sustenance to a focus on health and nutritional benefits. Rice (*Oryza sativa* L.), a staple food for over half of China's population, plays a critical role in human nutrition due to its essential nutrients. Consequently, increasing attention has been directed toward the nutritional value of rice, driving renewed interest in pigmented rice varieties, which contain higher levels of bioactive compounds and both micro- and macro-nutrients (Chen et al. 2019, Chen et al. 2022, Siroha et al. 2023, Nameirakpam et al. 2024). Among these, red rice has gained significant interest as a functional food due to its high content of proanthocyanidins (Shao et al. 2018) and phenolic compounds, which exhibit antioxidant properties. These bioactive components are associated with a reduced risk of chronic diseases related to oxidative stress, cardiovascular diseases, and neurological disorders (Chen et al. 2016, Samyor et al. 2017, Rathna Priya et al. 2019, Chen et al. 2022). As a result, red rice has emerged as a key player in the market for nutritionally enriched rice.

The brown planthopper (*Nilaparvata lugens* Stål, BPH) and rice blast caused by *the fungus Magnaporthe oryzae* are among the most destructive pests and diseases, significantly threatening rice yield stability in China. Developing new rice varieties with BPH and blast resistance is a critical strategy for achieving sustainable rice production. However, there is a notable lack of high-yielding red rice varieties with these resistance in Guangdong Province. The *Bph32* gene, which originates from the highly resistant red rice variety Rathu Heenati (RH), confers strong resistance to BPH populations in Guangdong (Hu et al. 2015, Hu et al. 2016). This gene has been successfully utilized to develop a moderately BPH-resistant red rice variety, Meilihong, through the backcross combination Hemeizhan///RH/Hemeizhan//Hemeizhan. However, this variety was not

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approved for release due to its susceptibility to blast disease in the Guangdong Province rice regional trials of 2016 and 2017. To address this limitation, two high-yielding and blast-resistant varieties (Huangguangyouzhan and Yehesimiao) were used as donors for the *Pi2* resistance gene. Through marker-assisted selection and agronomic trait selection (e.g. heading date, plant height, leaf color transformation, number of effective panicles, and seed setting rate), a new indica red rice variety, Hehongzhan 2, was developed. This variety exhibits improved blast resistance, moderate BPH resistance, high yield, superior agronomic traits, and broad adaptability. In this article, the breeding process, characteristics, and key cultivation techniques are described for this variety.

PEDIGREE AND BREEDING METHOD

The variety Hehongzhan 2 was developed by the Rice Research Institute of Guangdong Academy of Agricultural Sciences (RRI-GAAS) through the deployment of the BPH resistance gene *Bph32* and blast resistance gene *Pi2*. The breeding pedigree of Hehongzhan 2 is illustrated in Figure 1.

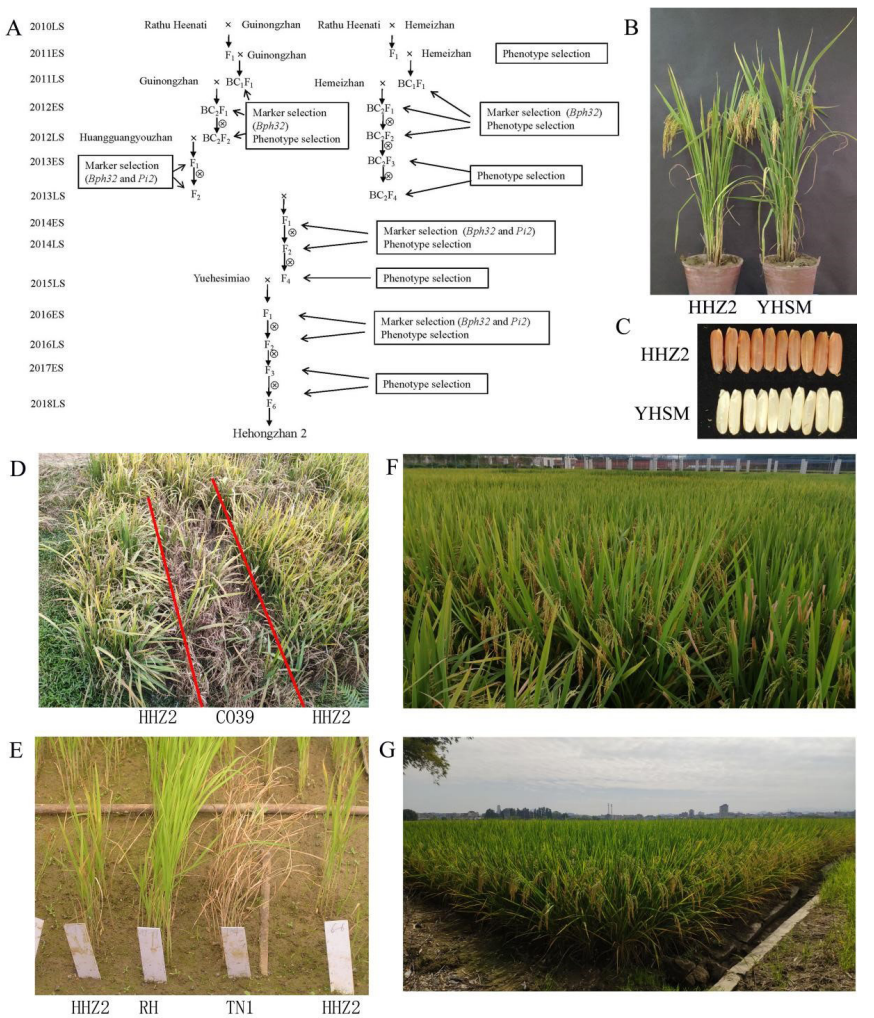

Figure 1. The breeding pedigree and the resistance to blast and BPH of Hehongzhan 2. A. The breeding process of Hehongzhan 2. B, C. Plant and brown rice of Hehongzhan 2 (HHZ2) and its female parent Yuehesimiao (YHSM). D. Blast resistance of HHZ2 under natural infection conditions in the blast hot-spot of Conghua (Guangzhou), in the late season of 2019, CO39, the susceptible control. E. BPH resistance of HHZ2 at the seedling stage, RH, the resistance control. F. HHZ2 in yield tests at the experimental field of RRI-GAAS (Guangzhou), in the late season of 2019. G. The cultivation of HHZ2 in Jieyang, Guangdong Province, in the early season of 2022.

In 2010, the *Bph32* gene was introgressed from RH into two super rice varieties, Hemeizhan (HMZ) and Guinongzhan (GNZ), using a marker-assisted backcross approach (Hu et al. 2015, Hu et al. 2016). In the BC_2F_2 generation, two markers (RM589 and RM8072) were used to select individuals homozygous for *Bph32* within both HMZ and GNZ genetic backgrounds. Plants with desirable plant architecture were selected and self-pollinated to produce BC_2F_3 lines. However, all BC_2F_3 lines, including two red rice lines, were susceptible to blast in natural infection tests conducted in a blast hot-spot (Conghua, Guangzhou). These lines also exhibited poor performance in yield and premature leaf senescence. Simultaneously, one BC_2F_2 plant from the GNZ background, which was resistant to BPH, was crossed with the elite rice variety Huangguangyouzhan. Huangguangyouzhan carries the *Pi2* gene and exhibits high blast resistance, high yield and good grain quality. The F_1 plants were cultivated in the early season of 2013, and the F_2 population was grown in the late season of the same year. Molecular markers for *Bph32* (RM589 and RM8072) and *Pi2* (RM527) were used to select the F_2 plants homozygous for both genes. One elite plant homozygous for *Bph32* and *Pi2* was crossed with a red rice BC_2F_4 plant (homozygous for *Bph32* in the HMZ background). Their F_1 plants were cultivated in the early season of 2014, and elite F_1 plants were self-pollinated to produce the F_2 generation. Using KASP markers (*Bph32* and *Pi2*) and agronomic trait selection, the red rice F_2 plants homozygous for both genes were selected and self-pollinated to generate F_3 lines. The red rice F_3 plants with desirable agronomic traits were further self-pollinated to produce the F_4 generation. However, these F_4 lines exhibited excessive plant height (over 120 cm) and loose plant architecture, necessitating further improvement.

In the late season of 2015, the elite *indica* rice variety Yuehesimiao was selected as the female parent. Yuehesimiao carries the *Pi2* gene and exhibits high blast resistance, high grain quality, semi-dwarf, semi-compact plant architecture, and excellent maturity color transition in South China. It was crossed with a red rice F_4 line carrying *Bph32* and *Pi2* to produce F_1 plants. Semi-dwarf, semi-compact F_1 plants were selected and self-pollinated to produce the F_2 generation. From the F_2 population, red rice plants homozygous for *Bph32 and Pi2* with a semi-dwarf, semi-compact plant architecture were selected to produce F_3 lines. In the late season of 2017, the F_3 lines were evaluated for field resistance to blast in the blast hot-spot of Conghua. Blast-resistant red rice plants with semi-compact architecture, high yield, and good maturity color transition were selected and advanced to the F_6 generation. One elite F_6 line was evaluated for yield performance in the late season of 2019 at the RRI-GAAS experimental farm (Guangzhou). The trial was arranged in a randomized complete block design with three replications and a plot area of 11.20 m². Seeds were sown on July 22, with heading on October 6, resulting in a total growth period of 115 days. The line yielded 6875 kg ha-1, representing a 7.94% increase over the control rice variety Yuejingsimiao 2 (the late-maturing rice group control in regional trial). The line exhibited excellent maturity color transition and resistance to panicle blast in the blast hot-spot (Figure 1). This line was designated Hehongzhan 2.

Hehongzhan 2 was evaluated as a special rice variety in two consecutive years of late-season regional trials in Guangdong Province, including the 2020 initial test, the 2021 retest, and the 2021 production trial. The trials were conducted at five locations: Chaozhou (eastern Guangdong), Zhaoqing (western central Guangdong), Jiangmen (central Guangdong), Yangjiang (western Guangdong), and Zhanjiang (western Guangdong). Both the initial test and retest were arranged in a randomized complete block design with three replications and a plot area of 13.34 m². The production

Table 1. Yield performance (kg ha^{-1}) of Hehongzhan 2 in Guangdong Province regional trials of 2021-2022

Trial site	Initial test of 2020			Retest of 2021			Production test of 2021		
	Hehongzhan 2	CK[1]	Increase (%)	Hehongzhan 2	CK	Increase (%)	Hehongzhan 2	CK	Increase (%)
Chaozhou	6114.2	5724.0	6.82	6624.2	5559.0	19.16	5637.0	5457.0	3.30
Zhaoqing	7179.3	5754.0	24.77	5941.5	5724.0	3.80	6414.0	5673.0	13.06
Jiangmen	6496.7	5754.0	12.91	6174.2	5461.4	13.05	5363.1	4971.6	7.87
Yangjiang	6676.7	5423.9	23.10	4906.2	4373.7	12.18	6459.9	4904.7	31.71
Zhanjiang	5805.9	5618.4	3.34	5356.4	4696.2	14.06	5423.1	4777.2	13.52
Average	6454.5	5654.9	14.19**	5800.5	5162.9	12.45**	5859.5	5156.7	13.89

[1] CK: Control variety, Yuehongbao. ** represnts a significant difference at $P < 0.01$.

trial was conducted in a randomized arrangement without replication, with a plot area of 333.5 m². Yuehongbao was the control variety in the regional trials.

Additionally, distinctness, uniformity, and stability (DUS) testing of Hehongzhan 2 was conducted by RRI-GAAS, in the late seasons of 2020 and 2021. Hehongzhan 2 exhibited an upright and compact plant architecture with green basal leaf sheaths, erect flag leaves, and an average stem length of 94.46 cm (Figure 1).

TRAIT PERFORMANCE

Hehongzhan 2 is a thermosensitive *indica* red rice variety suitable for double-season cultivation in Guangdong. It has a full growth period of 129-131 days in the early season and 112-114 days in the late season. In two-year regional trials, Hehongzhan 2 exhibited the following agronomic traits: a growth period of 112-114 days (0-2 days longer than the control variety, Yuehongbao), a plant height of 114.3-114.8 cm, medium plant architecture, medium tillering ability, strong lodging resistance, and moderate cold tolerance. It produced 219-231 effective panicles per m², with a panicle length of 22.5-23.1 cm, 139-144 grains per panicle, a fertilization rate of 84.2%-86.2%, and a thousand-grain weight of 26.0-26.8 g.

Yield Performance: In the 2020 and 2021 late-season regional trials, Hehongzhan 2 achieved average yields of 6454.5 kg ha^{-1} and 5800.5 kg ha^{-1}, reflecting 14.18% and 12.37% yield increases, respectively, compared to control variety. The yield gains over two consecutive years were statistically significant ($P < 0.01$) across all trial locations. During the 2021 production trial, Hehongzhan 2 recorded the average yield of 5859.5 kg ha^{-1}, a 13.63% improvement over the control (Table 1). The crop's daily yield efficiency ranged from 50.88 to 57.63 kg ha^{-1}, demonstrating both consistency and high-yield stability across different growing conditions.

Disease Resistance Performance: The resistance of Hehongzhan 2 to blast and bacterial blight was evaluated by the Plant Protection Research Institute of the Guangdong Academy of Agricultural Sciences (PPRI-GAAS) in the tow-year late-season regional trials. The resistance frequency to three blast populations at the seedling stage during indoor inoculation was 91.1%-91.4%. Field evaluations showed a leaf blast rating of 1.3-1.75 and a panicle blast rating of 1.5-2.0 (with a maximum single plot rating of 3), resulting in a comprehensive evaluation of high resistance to rice blast (Table 2, Figure 1). However, Hehongzhan 2 was susceptible to bacterial blight, with a disease score of 7 for the IX strain.

BPH Resistance Performance: Hehongzhan 2 exibited moderate resistance to brown planthopper (BPH) at the seedling stage, with a resistance score of 4.9. In comparison, its parent variety Yuehesimiao was susceptible, with a resistance score of 6.5 (Figure 1).

Rice Quality: The rice quality of Hehongzhan 2 was tested by the Quality Supervision and Testing Center for Rice and Products of Guangdong Province in the two-year late-season regional trials.The main quality indices included: head rice percentage of 61.0%-64.2%, length-to-width ratio of 3.2, chalkiness degree of 1.5%-3.5%, Grade 2 translucency,

Table 2. Blast resistance scores of Hehongzhan 2 in two-year late-season Guangdong Province regional trials

Year	Variety	Leaf blast[1]	**Neck blast[1]**	**Maximum neck blast**	**Comprehensive evaluation**
2020	Hehongzhan 2	1.75	2	3	highly resistant
	Yuehongbao(CK)	1.75	5	9	moderately resistant
2021	Hehongzhan 2	1.3	1.5	3	highly resistant
	Yuehongbao(CK)	2	4	9	moderately resistant

[1] leaf blast, neck blast: resistance scores were 1 for highly resistant and 9 for highly susceptible.

Table 3. Rice quality traits of Hehongzhan 2 in the Guangdong Province regional trials

Year	**Percentage of brown rice** (%)	**Percentage of polished rice** (%)	**Chalkiness degree** (%)	**Translucency**	**Alkali spreading value**	**Gel consistency** (mm)	**Amylose content** (%)	**Ratio of length and width**
2020	80.7	61.0	1.5	2	7.0	41	26.1	3.2
2021	81.2	64.2	3.5	2	7.0	70	27.3	3.2

alkali spreading value of 7, gel consistency of 40-70 mm, and amylose content of 26.1-27.3% (Table 3). Based on these results, the rice quality of Hehongzhan 2 met the ordinary standard of the Ministry of Agriculture and Rural Affairs, China.

CULTIVATION TECHNIQUES

Hehongzhan 2 is suitable for cultivation in both early-season and late-season in Guangdong (Figure 1). To optimize yield, the following key practices are recommended: (1) Optimal sowing time: For early-season cropping, sow in early March, delaying if necessary to avoid grain maturity coinciding with the Dragon Boat Rain during grain maturity. For late-season cropping, sow in mid-to-late July. (2) Fertilizer application: Fertilizer application should include 135 kg ha^{-1} of pure nitrogen, with a nitrogen, phosphate, and potash ratio of 1:0.4:0.8. The nitrogen application strategy should follow a ratio of 5:3:2 for basal fertilizer, tillering fertilizer, and panicle fertilizer. (3) Water management: Timely drying of paddy field should be implemented. During the later stages of growth, maintaining proper soil moisture is essential to avoid premature water withdrawal. (4) Harvest management: For early-season cropping, harvesting on time and proper drying are crucial to prevent pre-harvest sprouting, especially during the rainy season. For late-season cropping, avoid early irrigation cessation and harvest at full grain maturity.

FOUNDATION SEED PRODUCTION

Hehongzhan 2 was approved by the Guangdong Province Crop Variety Review Committee in 2023 (Approval No. Yue rice 20220073) and has been submitted for new plant variety rights to the Ministry of Agriculture and Rural Affairs, China (Application number 20231003414). The seeds of Hehongzhan 2 are preserved in the National Crop Gene Repository (Beijing). Since March 2023, the cultivar has been authorized for cultivation in Guangdong Province. Foundation seeds are produced by RRI-GAAS and supplied to grain producers.

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DATA AVAILABILITY

The datasets generated and/or analyzed in this study are available from the corresponding author upon reasonable request.

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