Breeding of a High-quality Hybrid Rice Combination Lvhanliangyou 888 with Drought and Heat Resistance

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Abstract Lvhanliangyou 888 is a new hybrid rice combination jointly bred by the Institute of Rice Research of Anhui Academy of Agricultural Sciences and Anhui Agricultural University. It was developed using Wan 28S as the female parent and Lvhui 888 as the male parent, and was approved by Anhui Provincial Crop Variety Approval Committee in 2023. Lvhanliangyou 888 possesses excellent characteristics such as high quality, drought resistance, heat resistance, disease resistance, and lodging resistance. It is suitable for promotion and cultivation as a water-saving and drought-resistant rice variety in the single-season rice areas of Anhui Province. This paper describes the breeding process, characteristics, and key cultivation points of Lvhanliangyou 888.

Key words Drought resistance; High quality; Heat resistance; Hybrid rice; Lvhanliangyou 888

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Rice is one of China's vital grain crops. According to data from the National Bureau of Statistics in 2023, the national rice output reached 206.6 million t, accounting for 29.7% of the total grain output of 695.41 million t, nearly a third of the total[1]. As an important rice-producing area in China, Anhui Province consistently maintains a substantial rice cultivation area[2-3]. As one of the countries with relatively scarce water resources globally, China faces an increasingly prominent contradiction between the substantial freshwater supply required for rice production and the actual carrying capacity of water resources. Water resource constraint has become a major bottleneck restricting the sustainable development of China's rice industry. In recent years, global warming has led to frequent high-temperature heat damage, posing a serious threat to rice production. High temperatures not only affect rice pollen fertility and the fertilization process, leading to a reduction in seed-setting rate, but also accelerate plant senescence and reduce grain filling rate and grain weight, severely impacting both yield and quality[4-5]. In response to increasingly severe resource and environmental challenges, developing water-saving and drought-resistant rice has become an important pathway for ensuring food security[6]. Particularly in key rice-producing areas such as Anhui Province, the combined stress of seasonal drought and high temperatures poses a significant threat to single-season rice production[7]. There is an urgent need to address this challenge by developing water-saving, drought-resistant, and heat-tolerant rice varieties, as well as supporting stress-resistant cultivation technologies[8]. Against this backdrop, breeding new rice varieties that combine high quality, stress tolerance and high yield holds significant strategic importance for alleviating regional water resource pressure and ensuring food security[9-11]. Lvhanliangyou 888 was approved by Anhui Provincial Crop Variety Approval Committee in 2023 (Approval Number: Wan Shen Dao 2023Z006) and is suitable for promotion and cultivation as a water-saving and drought-resistant rice variety in the single-season rice areas of Anhui Province.

Breeding Process

Breeding process of the female parent Wan 28S

In the winter of 2010 in Lingshui, Hainan, 1892S was crossed as the female parent with Hua 37B as the male parent. In the main season of 2011 in Beijing, the F_1 generation was planted and seeds were harvested. In the winter of the same year in Sanya, Hainan, 1892S was backcrossed as the female parent with the F_2 generation as the male parent. In the main season of 2012 in Hefei, molecular testing was conducted on individual plants. In the winter of 2012 in Lingshui, 1892S was again backcrossed as the female parent with the target plants identified from testing as the male parent. Subsequently, molecular testing in the laboratory was combined with selection for agronomic traits and fertility in the field each year, and selfing was conducted continuously for purification. The line was essentially stabilized in the winter of 2015 in Lingshui, Hainan, and test-crossed with multiple restorer lines. The resulting combinations underwent plot evaluation in the main season of 2016 in Bengbu, Anhui. In the winter of 2016, the line was propagated in Lingshui, Hainan, showing stable and uniform performance in the field. Thus, an indica rice thermosensitive genic male sterile line was successfully developed and named Wan 28S. In 2018, Wan 28S passed the on-site technical identification for major crop sterile lines in Anhui Province. Wan 28S exhibits

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characteristics such as disease resistance, lodging resistance, and can produce combinations with superior grain quality.

Breeding process of the male parent Lvhui 888

Lvhui 888 was developed by Anhui Agricultural University using Huanghuazhan as the recurrent parent and Qisiyingzhan as the donor parent through hybridization and backcrossing. Beginning with the BC_1F_2 generation, the plants underwent four generations of sequential selection: first drought stress screening, then two consecutive generations of high-yield and high-quality screening, and finally another round of drought stress screening. This was followed by two generations of purification, and the line was stabilized at BC_1F_7, resulting in an excellent new strain. Lvhui 888 exhibits characteristics such as drought tolerance, high quality, and strong combining ability.

Hybrid combination Lvhanliangyou 888

In the summer of 2018, the Institute of Rice Research of Anhui Academy of Agricultural Sciences and Anhui Agricultural University used Wan 28S and Lvhui 888 to develop the new hybrid combination Lvhanliangyou 888. During the summers of 2019 – 2020, Lvhanliangyou 888 participated in the multi-site heterosis identification test of new hybrid rice combinations organized by Institute of Rice Research of Anhui, Academy of Agricultural Sciences within Anhui Province. Its comprehensive performance in yield, resistance, and grain quality was favorable. In the summers of 2021 – 2022, Lvhanliangyou 888 was recommended for and participated in Anhui Province's independent trials for new water-saving and drought-tolerant rice varieties. It passed the provincial approval for major crop varieties in 2023, with the approval number 2023Z006.

Characteristics and Traits

High yield performance

In the 2021 production trial of Anhui Province's independent trials for new water-saving and drought-tolerant rice varieties, Lvhanliangyou 888 achieved an average yield of 10 080.9 kg/hm^2, representing a 23.82% increase compared with the control variety (Lvhan 1). In the 2022 production trial, its average yield was 9 048.0 kg/hm^2, showing a 16.27% increase compared with the control variety (Lvhan 1) (Table 1).

Table 1 High yield performance and main agronomic traits of Lvhanliangyou 888

Variety	Year	Plant height//cm	Total number of grains per panicle	Effective panicles 10^4/hm^2	Seed-setting rate//%	Thousand-grain weight//g	Whole growth period//d	Yield kg/hm^2
Lvhanliangyou 888	2021	123.9	185.1	295.5	91.3	24.8	123.3	10 080.9
	2022	120.8	207.1	352.5	84.2	22.5	116.3	9 048.0
Lvhan 1 (control)	2021	108.1	146.9	301.5	91.8	26.4	112.4	8 142.0
	2022	107.4	137.2	334.5	85.9	25.2	105.6	7 782.5

Main agronomic traits

Lvhanliangyou 888 is a medium indica two-line hybrid rice variety. In Anhui Province, with direct seeding in early June, its average whole growth period was 119.8 d, which was 10.8 d longer than that of the control variety (Lvhan 1). It showed an average plant height of 122.4 cm, an effective panicle density of 3.24 million per hectare, a grain number of 196.1 per panicle, a seed-setting rate of 87.8%, and a 1 000-grain weight of 23.7 g.

Main quality indices

In the 2021 – 2022 independent trials for water-saving and drought-resistant rice varieties in Anhui Province, Lvhanliangyou 888 was grown, managed, and sampled under unified conditions. Tested by Anhui Rice and Product Quality Testing Center, the 2021 results showed a brown rice rate of 80.4%, a head rice rate of 71.2%, a chalkiness degree of 0.6%, an amylose content of 16.9%, gel consistency of 75 mm, a transparency grade of 3, and an alkali spreading value of 5.3. The 2022 results were as follows: brown rice rate 80.4%, head rice rate 71.1%, chalkiness degree 1.6%, amylose content 14.9%, gel consistency 74 mm, transparency grade 1, and alkali spreading value 5.8 (Table 2). According to the ministerial standard *Cooking Rice Variety Quality* (NY/T 593-2013), Lvhanliangyou 888 meets the quality requirements for third-grade cooking rice varieties.

Table 2 Main quality indices of Lvhanliangyou 888

Variety	Year	Brown rice rate//%	Milled rice rate//%	Head rice rate//%	Grain length mm	Length-width ratio	Chalky grain percentage %	Chalkiness degree %	Amylose content	Gel consistency mm	Transparency grade grade	Alkali spreading value//grade
Lvhanliangyou 888	2021	80.4	73.3	71.2	5.9	2.8	4	0.6	16.9	75	2	5.3
	2022	80.4	73.6	71.1	6.0	2.9	9	1.6	14.9	74	1	5.8
Lvhan 1 (control)	2021	79.4	71.7	52.1	6.7	3.1	43	5.2	25.4	70	3	5.1
	2022	79.0	71.3	58.8	6.3	3.0	29	5.9	24.9	51	2	5.7

Disease resistance

Samples were uniformly collected during the 2021 – 2022 independent trials for water-saving and drought-resistant rice varieties in Anhui Province. Lvhanliangyou 888 was evaluated for disease resistance by Institute of Plant Protection and Agricultural Product Quality Safety, Anhui Academy of Agricultural Sciences.

Specifically, in 2021, Lvhanliangyou 888 exhibited a highest recorded panicle blast grade of 3, an average comprehensive resistance index of 3.3 to rice blast, a peak diseased panicle rate of 17.0% for false smut, and a bacterial blight grade of 7. In 2022, it exhibited a highest recorded panicle blast grade of 3, an average comprehensive resistance index of 3.1 to rice blast, a peak diseased panicle rate of 6.0% for false smut, and a bacterial blight grade of 7 (Table 3). Evaluated by Research and Development Center of Rice Cropping Technology, China National Rice Research Institute, its drought resistance index was 0.81 in 2021, with a drought resistance level of grade 3. Assessed by Water - Saving and Drought - Resistance Rice Identification Center, Shanghai Agrobiological Gene Center, its drought resistance index was 0.74 in 2022, also with a drought resistance level of grade 3. In 2022, evaluated by Institute of Rice Research, Anhui Academy of Agricultural Sciences, its heat tolerance index at the heading stage was 1.03, with a heat tolerance level of grade 3 (relatively strong).

Table 3 Main disease resistance indices of Lvhanliangyou 888

Year	Rice blast				False smut			Bacterial blight		Drought resistance		
	Panicle blast loss ratio//%	Disease grade	Evaluation	Average comprehensive resistance index	Diseased panicle rate//%	Disease grade	Evaluation	Disease grade	Evaluation	Drought resistance index	Drought resistance grade	Evaluation
2021	12.8	3	MR	3.3	17.0	7	S	7	S	0.81	3	MR
2022	11.0	3	MR	3.1	6.0	5	MS	7	S	0.74	3	MR

Key Points of Cultivation Technology

Timely sowing and reasonable planting density

Lvhanliangyou 888 is suitable for cultivation as a water-saving and drought-tolerant rice variety in the single-season medium rice areas of Anhui. It can be grown by seedling transplanting (manual or mechanical) or direct seeding. Lvhanliangyou 888 has a long direct seeding window, which spans from late April to early June. It is generally recommended to complete direct seeding by June 15, following a previous crop of wheat or rapeseed. For direct seeding in paddy field, the seeding rate ranges from 15 to 30 kg/hm^2. For dry direct seeding, it ranges from 30 to 45 kg/hm^2. Lvhanliangyou 888 is typically transplanted at a seedling age of around 30 d and a leaf age of 4 - 5 leaves. In transplanting fields, 1 - 2 seedlings are transplanted per hill using a plant spacing of 16.7 cm × 23.3 cm or 16.7 cm × 26.6 cm.

Scientific water management and rational fertilization

Scientific water management conserves water resources and contributes to environmentally harmonious and sustainable development[12-13]. In transplanting fields, shallow water should be maintained during transplanting, and an appropriate water level is required for seedling survival. Alternating wet and dry conditions are beneficial to tillering. Field drying should be conducted timely, while avoiding water cutoff too early in the later stages. In direct seeding fields, the field must remain moist during the sowing, booting (heading), and grain-filling stages, and a shallow water layer can be maintained during high-temperature periods. Lvhanliangyou 888 requires a medium to high level of fertilizer input. A scientific formulation of nitrogen, phosphorus, potassium, and micronutrients should be applied, and the fertilization principle involves sufficient base fertilizer and surface fertilizer, early application of tillering fertilizer, and increased application of panicle and grain fertilizer. If conditions permit, an appropriate amount of well-decomposed high-quality organic fertilizer can be applied, while appropriately reducing the amount of chemical fertilizer. The results of the Second National Soil Survey indicate that soils in northern China (including areas along the Huai River and between the Yangtze and Huai Rivers) are generally deficient in zinc. Direct-seeding rice is more sensitive to soil zinc deficiency compared with transplanted rice. Applying a small amount of zinc fertilizer can effectively enhance rice stress tolerance and improve grain quality. Generally, 15 - 30 kg/hm^2 of $ZnSO_4$ is applied during land preparation. Granular $ZnSO_4$ can be mixed with NPK compound fertilizer, while powdered $ZnSO_4$ should be uniformly mixed with fine soil and broadcast separately. It can also be applied as a foliar fertilizer by spraying. It should not be mixed alone with urea.

Control of diseases, pests and weeds

The principle of "prevention first, green control" should be adhered to. Monitoring and forecasting of diseases and pests should be strengthened to accurately track their occurrence and dynamics. Based on agricultural, biological, and physical control technologies, low-toxicity pesticides should be optimally selected for timely disease and pest control. For direct-seeding rice, comprehensive seed treatment with chemicals must be conducted before sowing to achieve sterilization and disinfection of seeds, protect against soil pests and rodent/bird damage from sowing through the seedling stage, and promote full and vigorous seedling establishment. Seed coating (seed dressing with seed coating agents) is prioritized as the most economical and effective method. It is advisable to select commercially available composite seed coating agents for rice or general crops (containing active ingredients such as fungicides and insecticides) for coating via machinery or manual application. In the areas along the Huai River and between the Yangtze and Huai Rivers, safe and efficient weed control technologies for direct-seeding rice following wheat or rapeseed crops should be based on "pre-emergence soil sealing", supplemented

as needed by "post-emergence chemical control", and manual weeding is adopted as a final measure for scattered weeds or local areas that are "missed".

Key Points of Seed Production Techniology

Timely sowing, reasonable planting density and effective isolation

Due to differences in the growth periods of the parents, sowing and transplanting schedules must be adjusted. In the seed production of Lvhanliangyou 888, the parents have different growth periods. The female parent (Wan 28S) is a two-line sterile line, with a sowing-to-heading period of approximately 67 d, a plant height of 75 cm, and an exserted stigma rate of 93.6% (favorable for outcrossing and seed setting). The male parent (Lvhui 888) is a conventional line, with a sowing-to-heading period of 87 d, a plant height of 100 cm, and abundant pollen production. For seed production in Bengbu, the parents require staggered sowing. The male parent should be sown in stages in early May (with an interval of 7 d), and it should be sown about 20 d earlier than the female parent to ensure flowering synchrony. The seeding rate for the female parent in the field is approximately 22.5 kg/hm^2, while that for the male parent is about 3.8 kg/hm^2. Seedlings are transplanted manually or by machine at a seedling age of around 25 d. The row ratio between the male and female parents is 2∶(12 – 14). The male parent was sown in two phases and transplanted in an alternating pattern of first – phase and second – phase seedlings, with a plant spacing of 16.7 cm × 26.7 cm, typically planting two rows. For the female parent, the planting spacing is 16.7 cm × 20.0 cm. It is important to maintain a distance of approximately 300 m between the seed production field and other rice fields, so aso to ensure strict isolation.

Scientific spraying of "920" and manual-assisted pollination

The parents are relatively sensitive to "920" (gibberellin), which should be applied in two stages. When approximately 5% of panicles emerge, "920" is sprayed on the male parent alone at a dosage of 30 g/hm^2. On the following day, "920" is sprayed on both parents at a dosage of 225 – 270 g/hm^2. Flowering time varies with different weather conditions. Generally, during the peak flowering period each day between 10:00 and 12:00, pollination should be conducted manually every half hour, for a total of 2 – 3 times, to maximize contact between the male parent's pollen and the female parent's stigmas. This process should be continued for 8 – 9 d consecutively[14].

Pest and disease control and rogueing for seed quality assurance

Pest and disease management should adhere to the principle of prevention first and integrated control, with particular attention to controlling stem borers, planthoppers, and kernel smut[8]. Seed purity is crucial. Therefore, rogueing in the seed production field must be strict and carried out as soon as off-type plants are detected. During the initial heading stage and before and after the application of "920", off-type or fertile plants should be promptly removed to prevent pollen contamination. During harvesting, tools should be cleaned promptly to prevent mechanical mixing. During drying, the site must be cleared to ensure it is free from contamination by external seeds.

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