

Shaochuan ZHOU, Decheng LU, Hong LI, Daoqiang HUANG, Ruowei MIAO

Research on the development of weed-suppressing rice varieties

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Abstract This study was conducted to develop weed-suppressing rice varieties in a weed-suppressing nursery by specific secondary metabolite markers of allelopathic potential. Weed-suppressing rice variety Feng-Hua-Zhan was screened out by a specific secondary metabolite marker of allelopathic potential. Weed-suppressing rice No.1, a new rice line with good quality, was also developed using this method. The genetic backgrounds and research directions of weed-suppressing rice varieties are discussed in this paper.

Keywords rice breeding, weed-suppressing, specific secondary metabolite

1 Introduction

An allelopathic rice variety could release chemicals to suppress the growth of accompanying weeds, and the utilization of allelopathic rice varieties is a potential alternative for controlling weeds. Water-soluble chemicals from allelopathic rice varieties are different from those of non-allelopathic rice varieties. Water-soluble chemicals could be detected rapidly by high performance liquid chromatography (HPLC). This discovery was made by Professor Kong, and he also defined the allelopathic index (AI) to describe the allelopathic potential of a rice variety (Kong and Hu, 2001; Kong et al., 2002; Zhu et al., 2003; Hu et al., 2004; Kong et al., 2004). Since then, researches on the correlation between AI and weed-suppressing rate in the field and the correlation between AI and agronomic traits have advanced (Lu et al., 2004; Zhou et al., 2005).

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Shaochuan ZHOU (✉), Decheng LU, Hong LI, Daoqiang HUANG, Ruowei MIAO
Guangdong Academy of Agricultural Sciences, Guangzhou 510640, China
E-mail: xxs123@163.com

This paper reports our research on the development of weed-suppressing rice varieties from 2002 to 2007.

2 Methods

2.1 Rice core germplasm breeding

Eighty-seven rice crosses among PI312777 (an allelopathic rice variety from the USA) and rice core germplasms such as Feng-Si-Zhan, Feng-Hua-Zhan, Lu-Te-Zhan and Wu-Shan-You-Zhan, were made from 2002 to 2005. Selections of filial generations were conducted in a weed-suppressing nursery, aided by a specific secondary metabolite marker of allelopathic potential (Lu et al., 2005). PI312777, as weed-suppressing CK, and Hua-Jing-Xian No.1, as weed-susceptible CK, were planted in all breeding processes.

2.2 Preparation of the rice weed-suppressing nursery

A rice weed-suppressing nursery was prepared in July, 2007. The nursery, covering an area of 0.34 hm² and which has been especially used for rice planting for many years, was located in the Baiyun Farm of the Guangdong Academy of Agricultural Sciences. Sandiness and poor fertility were typical of the nursery soil, with natural grass resources including barnyardgrass, sessile alternanthera, difformed galingale, smallflower galinsoga, Chinese sprangletop, sheathed monochoria, sand ammannia, rice galingale, and procumbent pennisetum. Barnyardgrass was the most dominant among the grasses in the nursery. Water and fertilizer management and disease and insect pest controls were conducted without chemical control of weeds or artificial weeding.

Three varieties, PI 312777, Feng-Hua-Zhan and Hua-Jing-Xian, were planted in randomized blocks with 2 replicates. Seedlings at 2.5-leaf-stage were transplanted by scattered-transplanting, with a density of 3×10^5 seedling·hm⁻². Urea at a dosage of 150 kg·hm⁻², composite

fertilizer at a dosage of $225 \text{ kg} \cdot \text{hm}^{-2}$ and K fertilizer at a dosage of $120 \text{ kg} \cdot \text{hm}^{-2}$, were applied 3 times within 25 d after transplanting.

2.3 Test of AI and investigation of weeds

AIs of the samples at the 6-leaf-stage were detected using the method of Kong et al. (2002). The HPLC apparatus used was HP-1100 (USA), the mobile phases of CH_3CN , CH_3COOH and H_2O , were chromatographically pure reagents. Weed and dry weight of grass were investigated at the mature stage. Weed-suppressing rate of each rice variety was calculated.

2.4 Selection of weed-suppressing rice variety

One hundred and fifty-five rice lines were selected by testing of AI and investigation of weeds in the field.

3 Results

3.1 Rice breeding method for weed-suppression

3.1.1 Agronomic traits of PI312777

The PI312777 grown in the Guangzhou region was of dwarf stem, with strong tiller ability, small panicle and low yield (Table 1). Its yield was as low as $3\text{--}3.38 \text{ t} \cdot \text{hm}^{-2}$. It had such poor qualities as low head rice rate, more

chalkiness, short grain shape and bad taste. It was highly susceptible to bacterial blight. Its amylose content measured by near infrared spectroscopy was 16.61%.

3.1.2 Correlation between AI and weed-suppressing ratio

Of the 155 lines, weed-suppressing variety Feng-Hua-Zhan and weed-susceptible variety Hua-Jing-Xian were selected. AIs of PI 312777, Feng-Hua-Zhan and Hua-Jing-Xian were 0.65, 0.65 and 0.22, respectively. Three varieties were planted in the weed-suppressing nursery and we found the existence of a positive correlation between AI and weed-suppressing ratio.

Tables 2–4 show that PI312777 and Feng-Hua-Zhan had strong weed-suppressing abilities. Table 4 shows that PI312777 and Feng-Hua-Zhan each had a strong suppressing effect on barnyard grass, sessile alternanthera and difformed galingal, but a light suppressing effect on smallflower galinsoga, Chinese sprangletop, sheathed monochoria, sand ammannia, rice galingale, and procumbent pennisetum.

Rice growing performance in the field showed that the weed-suppressing effect of PI312777 and Feng-Hua-Zhan appeared at the early stage and was related to allelopathic potential, water and fertilizer management, and space competition. Further, PI312777 and Feng-Hua-Zhan showed weed-suppressing effects within 25 d after being transplanted. With the decrease in weed-suppressing effect, accompanying grasses grew rapidly from the 26th to 45th day after transplanting. The biomass and leaf area of

Table 1 Agronomic traits of PI312777 in Guangzhou region

length of growth period/d	productive panicles/ $10^4 \cdot \text{hm}^{-2}$	plant height/cm	panicle length/cm	spikelets/no. per panicle	filled grain/no. per panicle	seed setting rate/%	1000-grain weight/g
115	4.80	85.2	20.9	80.86	69.56	86.03	21.74

Table 2 Multiple comparisons among the Nos. of weeds accompanying different rice varieties ($\text{plant} \cdot 10\text{m}^{-2}$)

variety	early-cropping season			late-cropping season		
	barnyard grass	others	total	barnyard grass	others	total
PI312777	0.83 b	57.33 b	58.16 b	8.5 b	243.0 b	251.5 b
Feng-Hua-Zhan	1.00 b	29.67 b	30.67 b	21.5 b	435.0 ab	456.5 b
Hua-Jing-Xian	3.17 a	359.84 a	363.01 a	116.5 a	630.0 a	746.5 a

Note: Different letters in the same column mean significant difference at 0.05 level.

Table 3 Multiple comparisons among dry mass weights of weeds accompanying different rice varieties ($\text{plant} \cdot 10\text{m}^{-2}$)

variety	early-cropping season			late-cropping season		
	barnyard grass	others	total	barnyard grass	others	total
PI312777	17.65 b	46.10 b	63.75 b	25.00 b	86.70 b	111.70 b
Feng-Hua-Zhan	17.45 b	76.45 b	93.90 b	66.80 b	130.00 b	196.65 b
Hua-Jing-Xian	76.69 a	213.35 a	290.20 a	338.35 a	278.30 a	616.65 a

Note: Multiple comparisons were made by DMRT, $P=0.05$.

PI312777 and Feng-Hua-Zhan at the early stage, especially of PI312777, were obviously higher than those of Hua-Jing-Xian. Due to the advantage of strong space competition, both PI312777 and Feng-Hua-Zhan showed a strong weed-suppressing effect.

Our experiment showed that Feng-Hua-Zhan was as good as PI312777 in AI and weed-suppression. Feng-Hua-Zhan could be involved in rice breeding programs for weed-suppression. AI and weed-suppressing rate were important traits of a simple and available method of weed-suppression breeding.

3.2 Weed-suppressing breeding in combination with a specific secondary metabolite and selection in the weed-suppressing nursery

3.2.1 Weed-suppressing rice lines

Until 2005, 127 promising rice lines were selected through AI, investigations of weeds in the nursery and rice agronomic traits (Table 5).

3.2.2 Promising lines

Tables 6 and 7 show the combination results of Lu-Te-Zhan/PI312777, Feng-Si-Zhan/PI312777, Feng-Hua-Zhan

/Cypress//PI312777 in the contrast experiment and their demonstration results in the late season of 2005.

3.2.3 Weed-suppressing No.1

Weed-suppressing No.1 was a new rice variety derived from the cross of Wu-Shan-You-Zhan×PI312777. Its AI and weed-suppressing rate were 0.56 and 65%, respectively. The contrast experiment in the late season of 2006 showed that the yield of weed-suppressing No.1 was $8.34 \text{ t} \cdot \text{hm}^{-2}$, significantly higher than that of CK Jing-Xian 89 by 21.50%. It was highly resistant to blast and relatively resistant to bacterial blight. Its main agronomic traits were 2.58 million productive panicles per hectare, 110 days from sowing to harvesting, a 99.8 cm plant height, 21.6 cm panicle length, 140.5 spikelets per panicle, 88.3% in seed setting rate, and 25.8 g in 1000-grain weight.

Its pre-trial yield in Guangdong Province in the late season of 2007 was $7.27 \text{ t} \cdot \text{hm}^{-2}$, higher than that of CK Jing-Xian 89 by 4.79%. It is now in the trial process in Guangdong Province in the late season of 2008.

4 Discussion

It is obvious that the weed-suppressing effects of PI312777 and Feng-Hua-Zhan cannot completely replace the

Table 4 Multiple comparisons among the Nos. of different weeds accompanying different rice varieties ($\text{plant} \cdot 10\text{m}^{-2}$)

variety	barnyard grass	sessile alternanthera	diffomed galingale	smallflower galinsoga	Chinese sprangletop	sheathed monochoria	sand ammannia	rice galingale	procumbent pennisetum
PI 312777	0.8 b	0.5 b	37.5 b	0.8	0	0	0	2.5	20
Feng-Hua-Zhan	1.0 b	1.0 b	0.65 b	1.5	1.5	1	0	1.5	7.5
Hua-Jing-Xian	3.15 a	5.5 a	328 a	1.5	8.5	1	0.5	10.5	12.5

Note: Multiple comparisons were made by DMRT, $P=0.05$. Smallflower galinsoga, Chinese sprangletop, sheathed monochoria, sand ammannia, rice galingale, and procumbent pennisetum showed no significant difference (without marked letters).

Table 5 Promising rice lines

cross combinations	generation	selected lines
Lu-Te-Zhan/PI312777	F6	13
Feng-Si-Zhan/PI312777	F6	24
Feng-Hua-Zhan/Cypress//PI312777	F5	16
Mei-Xiang-Zhan 8//Ai-Xiu-Zhan/PI312777	F5	19
Feng-Si-Zhan//Ai-Xiu-Zhan/PI312777	F5	7
Lu-Te-Zhan//Ai-Xiu-Zhan/PI312777	F5	10
Wu-Shan-You-Zhan/PI312777	F5	5
Wu-Shan-You-Zhan/PI312777	F4	4
PI312777/Mo-Li-Ruan-Zhan	F3	8
PI312777/Feng-Yue-Zhan	F3	4
Takaneshike/Wu-Shan-You-Zhan//PI312777	F3	9
Takaneshike/Wu-Shan-You-Zhan//Mo-Li-Xin-Zhan	F3	8

Table 6 Results of the contrast experiment in the late season of 2005

trait	Lu-Te-Zhan/PI312777	Jing-Xian 89 (CK)
yield/t·hm ⁻²	7.86	6.19
±CK1/%	+26.9%	–
productive panicles/10 ⁴ ·hm ⁻²	264	270
resistance to bacterial blight/class	3	4
plant height/cm	107.8	102.6
panicle length/cm	22	20.2
spikelets No./grain	156	188
seed setting rate/%	84.8	76.7
1000-grain weight/g	17.6	17.2
duration from sowing to harvesting/d	109	114
amylose content/%	14.2	–
AI	0.668	

Table 7 Results of demonstration in the late season of 2005

trait	Feng-Si-Zhan/PI312777	Feng-Hua-Zhan/Cypress/ PI312777	Feng-Hua-Zhan (CK1)	PI312777 (CK2)
yield /t·hm ⁻²	5.35	4.44	5.00	3.40
±CK1/%, ±CK2/%	+6.95, +57.14	-11.11, +30.61	–	–
productive panicles /10 ⁴ ·hm ⁻²	243	220.5	232.5	304.5
resistance to bacterial blight/ class	3	1–3	1	10
plant height/cm	96.8	94.5	92.3	82.2
panicle length/cm	21.03	21.84	22.07	19.74
spikelets No.	117.4	119.4	120.5	68.6
seed setting rate/%	78.4	82	89.6	86.7
1000-grain weight/g	22.83	20.38	19.3	21.74
duration from sowing to harvesting/d	110	105	105	108
AI	0.659	0.628	0.650	0.534

application of weeding chemicals. Our experiment showed that the weed-suppressing effects were obviously associated with many factors including pattern of transplantation, planting density, temperature at the early stage, and depth of water. Therefore, the solo weed-suppressing rice variety itself is not enough and the application of weed-suppressing rice variety could be promoted in combination with other integrated weed-control management schemes.

Weed-suppressing can be controlled by complicated genetic mechanisms (Kong and Hu, 2001; Zeng et al., 2003; Xu et al., 2003), but whether it is really controlled genetically needs further study.

Rice research has entered a post-genomic era. We suggest that genome-wide foreground and background selection at the molecular level is an effective tool for future weed-suppression breeding (Zhou et al., 2008).

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