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Growth and development characteristics of super-high-yielding mid-season japonica rice

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Abstract Rice is one of the most important food crops in China. The realization of the super-high-yielding (SHY) type has great significance in ensuring food security in this country. This study investigated the growth and development characteristics of the super-high-yielding rice (grain yield > 11 t/hm²). Four mid-season japonica rice cultivars (including lines): Lianjiating 2, Huajing 5, 0026 and 9823, were grown in the paddy field. Growth analysis was performed during the growth period, and yield components were determined at maturity. Results showed that SHY rice had more spikelets per panicle and higher filled-grain percentage than the high-yielding rice (CK, grain yield 8.98–9.16 t/hm²). There was no significant difference in the 1 000-grain weight between the super-high-yielding and the CK. Super-high-yield rice exhibited fewer tillers at the early growth stage (from transplanting to jointing), with a higher ratio of productive tillers to total tillers, when compared with the CK. The leaf area index (LAI), photosynthetic potential and dry matter accumulation were lower for the SHY rice than those for the CK at the early growth stage, and the differences were not significant between the two rice types at heading, but were greater in the former than the latter after heading. The root-shoot ratio at each growth stage, root bleedings from heading to maturity, grain-leaf ratio, translocation percentage of the matter from stems and sheaths and harvest index of super-high-yielding rice were greater than those of CK. The indexes for the growth and development of SHY mid-season rice population were suggested, i.e. total spikelets > 4.5 × 10⁴/m², filled-grain percentage > 90%, 1 000-grain weight > 26 g; ratio of productive tillers > 80%, leaf area index at heading 7.5–8.0, photosynthetic potential during the whole growth period > 5 × 10⁶ m²·d/hm², total dry matter weight at maturity > 22 t/hm², harvest index > 0.51; grain-leaf ratio (number of

spikelets per cm² leaf area) > 0.58; root-shoot ratio at heading > 0.25 and amount of root exudates > 5 g/m²·h. The regulation approaches and key cultivation techniques for raising the super-high-yielding population were also discussed.

Keywords mid-season japonica rice, super-high-yielding, growth and development, regulation approach

1 Introduction

Maximum tapping of heredity potentials and improving cultivation management techniques are always the two key points in agriculture (Peng et al., 1999; Lin and Zhang, 2002). Rice is a very important food crop and 50% of the world populations are fed with rice, and in Asia, 95% of the population depend on rice for food (FAO, 2004). Therefore, the genetics and cultivation of SHY rice have always been emphasized (Yuan, 1998; Zou et al., 2003; Zhen and Huang, 2003; Huang and Xu, 2004). Japan first put forward the assumption of the SHY heredity of rice in 1980 and drew up a plan of exploiting SHY crops and studying cultivation techniques the following year, aiming at realizing SHY goals for yield to reach 7.5–9.8 t/hm² in low-yielding regions and > 10 t/hm² in high-yielding regions by breeding potentially high-yielding varieties together with relevant cultivation techniques. The Ministry of Agriculture, P.R. China started the “CSHY (China-super-high-yielding)” Plan in 1996, in order to make SHY rice produce 15% more than CK rice, manufacture 9–10.5 t/hm² absolute output in 2000 and reach the yield goal of 12 t/hm² in 2005. China has presently already made major progress in SHY breeding and cultivation, and a series of SHY varieties or hybrid rice cultivars, the outputs of which can reach 12–17 t/hm² in small areas or at a particular climate (Yuan, 2000; Wang, 1998; Liu and Yuan, 2002), have been developed. However, most SHY rice varieties have not reached this high-yielding record and their outputs are also unsteady in different areas annually (Gu and Tang, 2001; Liu et al., 1996; Yang et al., 2002). We know little about the growth and development characteristics, diagnosis indexes and cultivation techniques of the SHY rice. The population

Translated from *Scientia Agricultura Sinica*, 2006, 39(7): 1336–1345
[译自: 中国农业科学]

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growth and development characteristics of four SHY mid-season japonica rice cultivars were observed in our experiment, aiming to provide a theoretical basis for SHY rice breedings and cultivation.

2 Materials and methods

2.1 Materials and cultivation conditions

The experimental materials were four mid-season japonica rice cultivars: Lianjiajing 1, Huajing 5, 0026 and 9823. Total leaf number was 17, internode number was 5, and the whole growth period was 150–155 d. In 2004, the four varieties were planted in Lianyungang National Regional Test Station, Jiangsu Gangbu Farm and Yuntai Farm (34°50' N, 119°25' E). The preceding crop was wheat, and soil type was viscose doras with organic matter of 23.0–26.0 g/kg, rapidly available nitrogen of 100–105 mg/kg, rapidly available phosphorus of 35–42 mg/kg and rapidly available potassium of 205–255 mg/kg. Irrigation condition was fine and the yearly yield was about 8–9 t/hm². The planting areas for the SHY rice cultivars 0026, 9823, Lianjiajing 1 and Huajing 5 were 0.14, 7.2, 5.6 and 3.7 hm², respectively. The rice seeds were sown on May 5, 2004 and the seedlings were cultivated on an upland field. They were transplanted on June 15, 2004 with row spacing of 30 cm and spacing within rows of 15 cm (two seed-seedlings per hill). 45 m³/hm² stable manure, 138 kg/hm² pure nitrogen, 600 kg/hm² ordinary super-phosphate (13% P₂O₅) and 120 kg/hm² potassium chloride (52% K₂O) were applied. Additional N fertilizer was applied according to chlorophyll meter (Soil and Plant Analysis Department, SPAD) or leaf color chart (LCC). The amount of pure nitrogen added for tillering of 0026, 9823, Lianjiajing 1 and Huanjing 5 was 27.6, 34.5, 34.5 and 27.6 kg/hm², respectively. The amount of N fertilizer used to promote flowering was 27.6, 51.8, 41.4 and 75.9 kg/hm², respectively and the amount of N fertilizer applied for protecting flowers was 55.2, 41.4, 55.2 and 27.6 kg/hm², respectively. In addition, 13.8 kg/hm² of grain N fertilizer was used in 0026. 120 kg/hm² of KCl was applied to the four varieties at jointing stage. The field was dried at the 12–13 leaf age, irrigated alternately after heading and flowering, and maintained with shallow water for the rest of the stages.

A plot in the SHY experiment field was selected to be CK where soil was viscose. Sowing time, reaping time and the varieties used were the same as the SHY rice cultivars. Methods of raising seedlings, planting density and fertilizer-water management were the same as conventional ones. Seedlings were raised in water upland for 35–40 d. Row spacing and spacing within rows were 20 cm and 17 cm, respectively. Two to three seed-seedlings per hill (three seed-seedlings for Huajing 5) were planted. 270–300 kg/hm² of pure nitrogen was applied at the ratio of 5:2:3 base-fertilizer:tillering-fertilizer:panicle-fertilizer and N:P₂O₅:K₂O ratio was 1:0.3:0.5, using phosphate and potash fertilizer as base fertilizer.

The field was drained at the 14–15 d leaf-age and moderate water was maintained for the rest of the stages.

2.2 Sampling and measuring

2.2.1 Stem and tiller development

Plants from twenty hills were taken as observation points in the field of SHY and HY, and three observation points were selected as replications. Stem and tiller development was investigated in the stages of transplanting, critical leaf-age for productive tillers, jointing, booting, heading and maturity.

2.2.2 Measurement of dry matter and leaf-area

Plants from ten hills were taken as sampling plots in the stages of transplanting, critical leaf-age for productive tillers, jointing, heading, milking, waxing and maturity. Green leaves, decayed leaves, stems, sheath and panicles (after heading), leaf area and dry matter weight were measured. Leaf area was classified as area of total leaves, effective leaf area and high-active leaf area. The measurements were repeated three times.

2.2.3 Measurement of root dry weight and root exudates

Plants from five hills were taken as sampling plots in the stages of transplanting, critical leaf-age for productive tillers, jointing, heading, milking, waxing and maturity with three replications. Root soil was excavated with a digging tool (30 cm long, 10 cm wide and 20 cm high), centered around the root stubble after cutting the above-ground part off, put into nylon bags (40-mesh), then washed with tap water followed by drying of the roots and weighing.

Plants from four hills were taken as sampling plots in the stages of heading, milking and waxing. The aerial part of each stem was cut off at a height of 12 cm above the soil line. Weighed absorbent cotton was placed on the wound, then it was covered with plastic film at 6 p.m. and weighed at 8 a.m. the next morning. The collected root exudates were calculated. All the tests were repeated three times.

2.2.4 Measuring yield and inquiring its components

For each cultivar and field type, plants from 100 hills were collected to count spike number before harvest, and plants from five hills were used to measure filled-grain percentage and 1 000-grain-weight. All the measurements were repeated three times. A combined harvester was used to reap rice and the yield was verified by an expert group.

2.2.5 Calculation and statistical method

Spikelets per panicle = grain yield/(panicles per unit × filled-grain percentage × 1 000-grain weight).

Photosynthetic potential (m²·d/hm²) = 1/2(L1 + L2) × (t2 - t1), where L1 is the first measurement of the leaf

area, L_2 is the second measurement of the leaf area (m^2/hm^2), t_1 is the first time (d), and t_2 is the second time (d) of measurement.

Spikelet-leaf area ratio = total spikelets/leaf area at heading stage;

Grain-leaf area ratio = total grains/leaf area at heading stage;

Grain weight/leaf (mg/cm^2) = grain yield/leaf area at heading stage;

Translocation ratio of stem and sheath = (stem-sheath dry weight at heading stage – stem-sheath dry weight at maturity stage)/stem-sheath dry weight at heading stage \times 100.

All the data collected were analyzed with SAS software, and least significant difference (LSD) method was used for the significance test.

3 Results and analysis

3.1 Yield and its forming components

The yield results of the four rice cultivars are listed in Table 1. Yields of all four SHY rice cultivars exceeded $11 \text{ t}/\text{hm}^2$, and the yield of 0026 reached $12.09 \text{ t}/\text{hm}^2$. The average yield of SHY ($11.46 \text{ t}/\text{hm}^2$) was 26.21% above the yield of HY ($9.08 \text{ t}/\text{hm}^2$), surpassing 15% of the SHY increasing-yield index (Yuan, 2000). Panicles per hectare of SHY were higher than that of HY, but the difference did not reach a significant level. Spikelets and filled-grain percentage of SHY were significantly higher than that of HY. There was little difference in the 1 000-grain weight between the two groups. The result indicated that increases in spikelets and filled-grain percentage are the key techniques for SHY cultivation.

3.2 Total tillers in each growth and development stage

Compared with CK, the stems and tillers of SHY rice were fewer at earlier stages, especially at jointing stage, but the number of stems and tillers of SHY was a little higher than that of HY from heading to maturity (Fig. 1). Stems and tillers of SHY at transplanting stage were 45% of the final panicle

number, being equal to the final panicle number at critical leaf-age for productive tillers, and reaching the highest point (120% of final panicle number) at earlier jointing stage, then decreasing smoothly and being equal to or a little higher than the final panicle number. The ratio of productive tillers to total tillers of SHY was above 80% (CK was only 60%–70%).

3.3 Leaf area, photosynthetic potential and dry matter accumulation

Similar to the changes in stems and tillers at each growth-development stage, the LAI (leaf area index) of SHY was smaller at earlier stages but greater at mid-to-later stages than that of CK (Fig. 2). LAI at N-n stage was around 3.5, 6.0–6.8 at jointing stage, 7.5–8.0 at heading stage, 6.5–7.0 at milking stage, 4.0–4.5 at waxing stage and 2.0–2.5 at mature stage. The effective leaf-area and higher-active leaf-area of SHY rice were about 96%–99% and 70%–72%, respectively, while the indexes of HY rice were 85%–91% and 63%–66%, respectively (Figs omitted). The results showed that the source of SHY rice was even superior to that of CK.

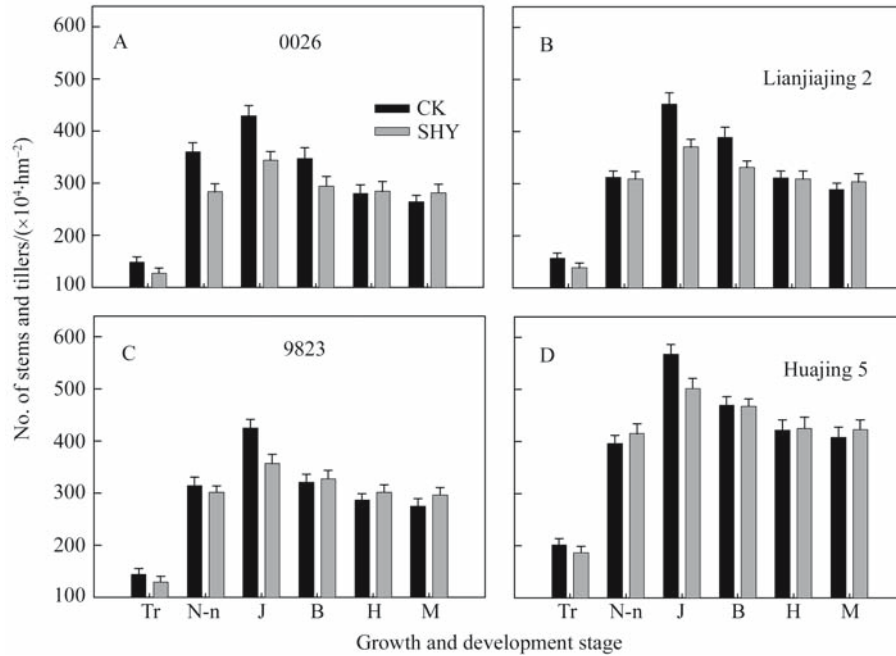
Similar to the changes in LAI (Fig. 3), the photosynthetic potential ($\times 10^4 \text{ m}^2 \cdot \text{d}/\text{hm}^2$) of SHY rice was 35–38 from transplanting to N-n stage, 65–70 from N-n to jointing stage, 250–260 from jointing to heading stage, around 110 from heading to milking stage, 90–95 from milking to waxing stage, 50–55 from waxing to maturity, >500 in the whole growth-development period and >250 from heading to maturity (Fig. 3).

Dry matter accumulation of SHY rice was less than that of CK before jointing, showing little significant difference at heading stage and very significant difference after heading (Fig. 4). Dry matter weight (t/hm^2) was 3.0–3.5 at N-n stage, 6.0–6.8 at jointing stage, 12.5–13.5 at heading stage, 17.5–18 at milking stage, 20–22 at waxing stage and 21.5–23 at mature stage. Dry weight at heading stage was about 60% of total dry weight, and the accumulation of dry weight from heading to maturity was about 40% of the total dry weight. The dry weight at heading stage of HY rice was about 65%–70% of the total dry weight, and the accumulation of dry weight from heading to maturity was about 30%–35% of the

Table 1 Grain yield and its forming components

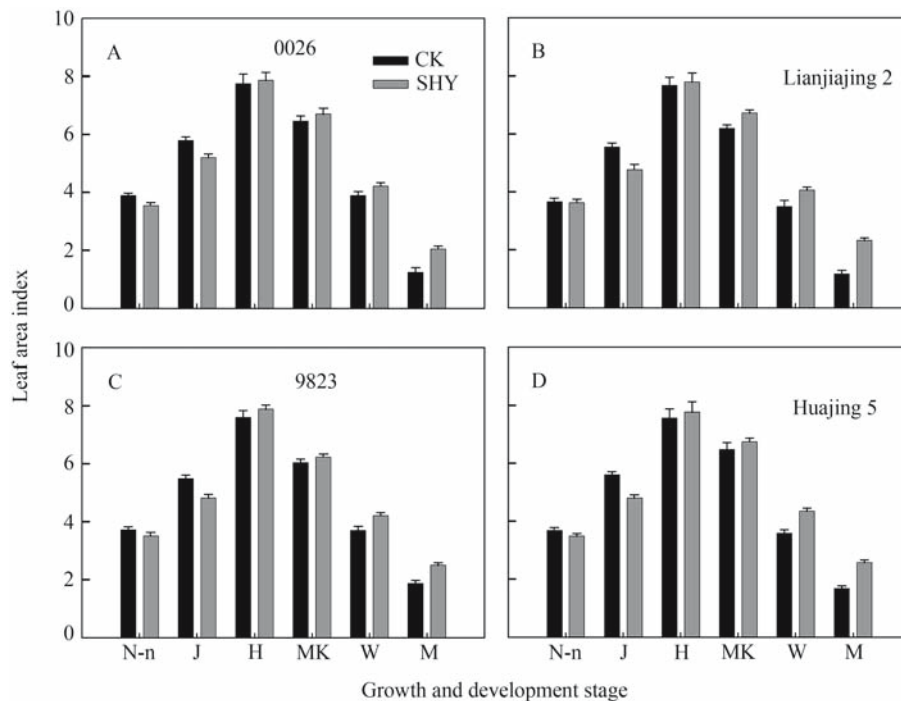
Cultivars	Type	Area/ hm^2	Grain yield/ $\text{t} \cdot \text{hm}^{-2}$	Panicles/ $\times 10^4 \cdot \text{hm}^{-2}$	Spikelets per panicles	Filled-grain percentage/%	1 000-grain weight/g
0026	CK	0.12	9.16	265	145.1	87.82	27.12
	SHY	0.14	12.09**	282	167.8**	94.52**	27.03
Lianjiajing 2	CK	0.15	9.15	289	137.6	88.21	26.08
	SHY	7.2	11.27**	303	151.3**	94.01**	26.15
9823	CK	0.15	8.98	275	142.2	84.59	27.14
	SHY	5.6	11.26**	297*	152.0**	91.73**	27.19
Huajing 5	CK	1.4	9.03	409	96.96	86.78	26.24
	SHY	3.7	11.21**	423	106.8**	94.67**	26.21

Notes: CK represents Control; SHY represents Super-high-yielding; *and ** indicate significant difference at 0.05 and 0.01 levels, respectively, compared with the control within the same cultivar; the same abbreviations are used in succeeding tables.



CK: Control; SHY: Super-high-yielding; Tr: Transplanting stage; N-n: Critical leaf-age for productive tillers; J: Jointing; B: Booting; H: Heading; M: Maturity

Fig. 1 Number of stems and tillers at each growth and development stage



N-n: Critical leaf-age for productive tillers; J: Jointing; H: Heading; MK: Milky stage; W: Waxy stage; M: Maturity; the same are below

Fig. 2 Leaf area index (LAI) at each growth and development stage

total dry weight. The ratio of stem and sheath dry weight to total dry weight of SHY rice was higher before heading and smaller after heading than that of HY rice. SHY rice was found to have accumulated more photosynthates before heading and exported more stored materials after heading.

3.4 Grain-leaf ratio, stem-sheath matter translocation ratio and harvest index

Sink-source ratio was expressed as grain-leaf ratio in this experiment. Spikelets, filled grain and grain weight (mg)

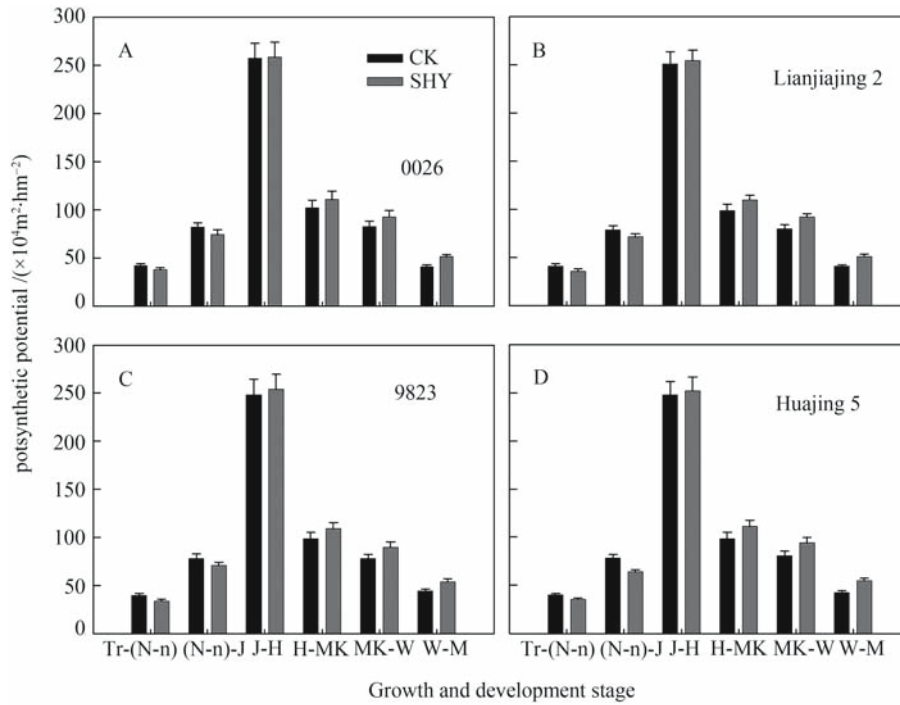


Fig. 3 Photosynthetic potential at each growth and development stage

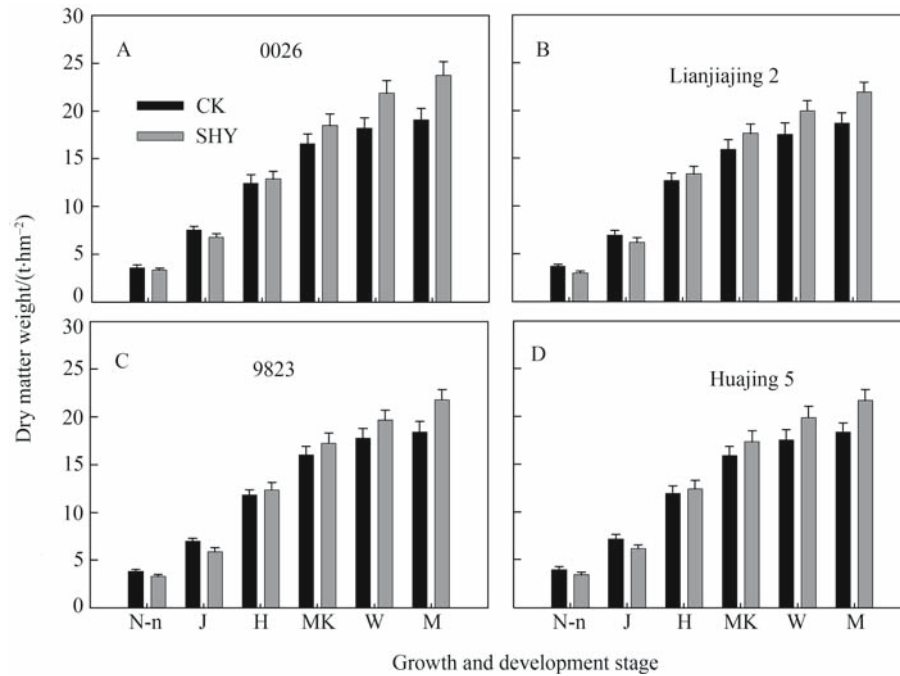


Fig. 4 Dry matter accumulation at each growth and development stage

per cm² of leaf area of SHY rice were 0.572–0.603, 0.524–0.570 and 14.29–15.40, respectively, which were significantly higher than those of CK (Table 2). The averages of stem-sheath matter translocation and harvest index of SHY rice were 11.47% and 0.515, being 8.5% and 6.96% higher than the relevant indexes of CK, respectively (Table 2).

3.5 Root-shoot ratio and root exudate

Root-shoot ratio became smaller with the growth and development (Fig. 5). Root-shoot ratios of SHY rice were 0.38–0.41 at N-n stage, 0.32–0.35 at jointing stage, 0.25–0.27 at heading stage, 0.20–0.22 at milking stage, 0.16–0.18 at

Table 2 Grain-leaf ratio, translocation ratio of matter in stems and sheaths and harvest index for super-high-yielding rice

Cultivars	Type	Grain-leaf ratio			Translocation ratio/%	Harvest index
		Spikelets per cm ² leaf area/cm ²	Filled grain per cm ² leaf area/cm ²	Grain Wt per cm ² leaf area /mg · cm ⁻²		
0026	CK	0.496	0.436	11.82	5.03	0.456
	SHY	0.603**	0.570**	15.40**	11.59**	0.509**
Lianjiajing 2	CK	0.518	0.457	11.93	3.92	0.485
	SHY	0.589*	0.554**	14.49**	10.64**	0.513**
9823	CK	0.515	0.436	11.83	0.98	0.488
	SHY	0.572**	0.524**	14.29**	11.84**	0.517**
Huaqing 5	CK	0.524	0.454	11.94	2.28	0.495
	SHY	0.582*	0.551**	14.45**	11.81**	0.519**

Note: Translocation ratio (%) = (dry weight of stems and sheaths at heading – dry weight of stems and sheaths at maturity)/dry weight of stems and sheaths at heading × 10

waxing stage and 0.14–0.16 at mature stage. Root-shoot ratios of SHY at each stage were all higher than those of CK, especially at the jointing stage when HY rice had many less tillers and could not form a good root system compared with SHY.

Similar to the changes of root-shoot ratio, root exudates became less and less with the grain filling process. Root exudate (g/m²·h) of SHY rice was 5.31–5.65 at heading stage, 4.91–5.32 at milking stage and 3.05–3.13 at waxing stage, while the indexes for HY rice were 4.72–5.03, 4.11–4.24 and 1.70–2.02, respectively. Root exudate of SHY rice was significantly higher than that of HY rice, especially at the later stages (Fig. 6). Powerful matter-production ability and the high harvest index of SHY rice were perhaps attributed to the more massive root system and higher root exudate.

4 Discussion

4.1 Growth and development characteristics and population indexes of SHY rice

Compared with high-yielding rice (yield: around 9 t/hm²), SHY rice (>11 t/hm²) mainly had the following growth-development characteristics: (1) total stems and tillers and dry matter accumulation were small at early stages, steady at middle stages and high at late stages, i.e. small production before jointing, similar to high-yielding rice at heading stage, and higher than high-yielding rice between jointing and maturity; (2) the yield components were steady with sufficient panicles, many spikelets and high filled-grain percentage; (3) source, sink and flow characteristics had high photosynthetic potential, high grain-leaf ratio, high matter translocation ratio and high harvest index; and (4) roots were characterized by a large quantity, high root-shoot ratio and strong root vitality. Indexes of SHY rice population are listed in Table 3 according to the results above, which may be regarded as references for SHY breeding and cultivation of mid-season japonica rice.

Table 3 Population indexes of super high-yielding mid-season japonica rice

Item	Index
Total spikelets/ × 10 ⁴ · m ⁻²	>4.5
Filled-grain percentage/%	>90
1 000-grain weight/g	26–28
The ratio of productive tillers to total tillers/%	>80
Leaf area index at heading	7.5–8
Total photosynthetic potential/m ² · d · hm ⁻²	>5 × 10 ⁶
Dry matter weight at maturity/t · hm ⁻²	>22
Dry matter weight from heading to maturity/t · hm ⁻²	>8
Grain-leaf ratio (Number of spikelets per 1 cm ² leaf area)	>0.58
Translocation ratio of matter from stems and sheaths/%	>11
Root-shoot ratio at heading	>0.25
Root exudates at heading/g · m ⁻² · h ⁻¹	>5
Harvest index	>0.51

4.2 Regulation methods of SHY rice

Greatly enlarging sink capacity is the premise to fulfill the SHY quality in rice. Increasing panicles and spikelets or increasing both can raise spikelets per unit area of soil. Cao et al. (1991) analyzed the source-sink characteristics of mid-season Indica rice used since 1950s in China. The results showed that panicles decreased slightly, while spikelets increased significantly from dwarf-stem varieties to modern varieties. Our study showed that panicles of SHY rice only increased slightly, but spikelets increased the most. The variety improvement and SHY cultivation practice indicated that enlargement of sink capacity depends on spikelets increasing per panicle. In the long run, increasing spikelets per unit area of soil will be limited eventually, and increasing spikelets per panicle could be the only way to enlarge its sink capacity.

There was generally a negative correlation between spikelets per panicle and filled-grain percentage (Mohapatra and Sahu, 1991). SHY rice could increase spikelet per panicle by 10.61% and raise filled-grain percentage by 6.9% compared with high-yielding rice. These results showed that panicles and spikelets really were not uncoordinated contradictions and they could be increased simultaneously for realizing SHY quality in rice. SHY rice had similar LAI to HY rice, but its grain-leaf ratio was larger than that of HY rice. High grain-leaf ratio showed that SHY rice had less unproductive tillers

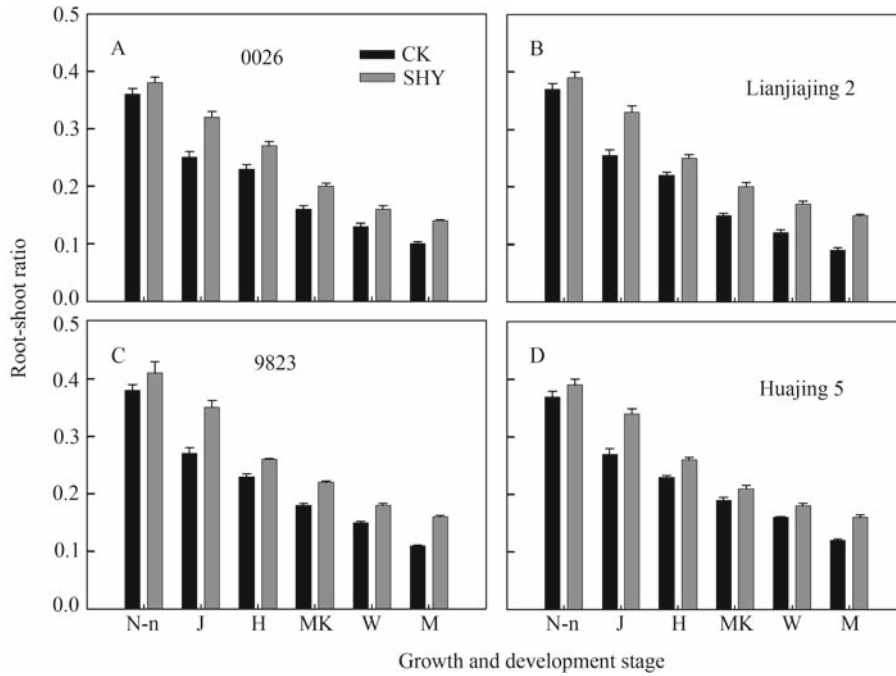


Fig. 5 Root-shoot ratio at each growth and development stage

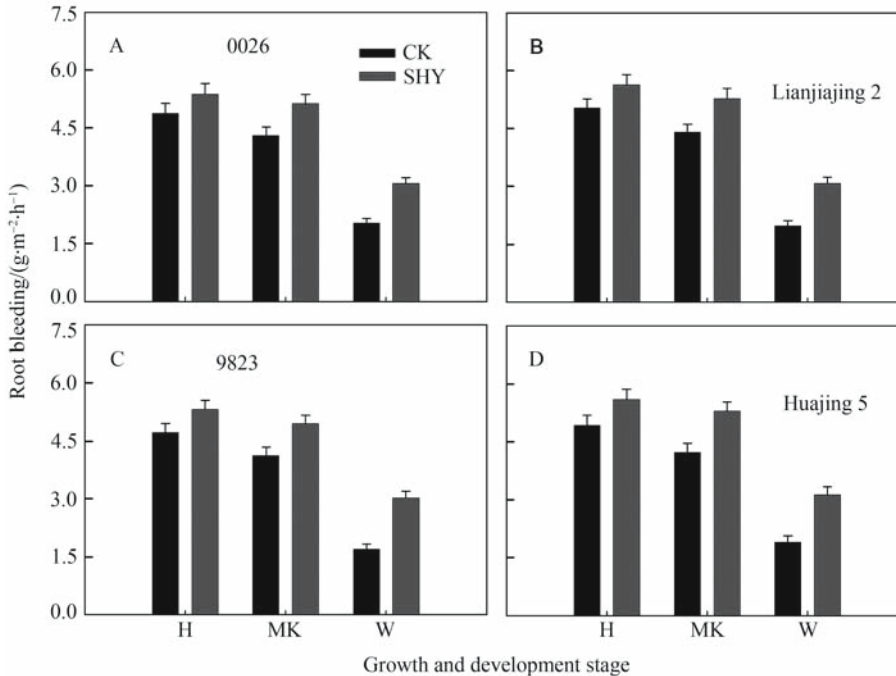


Fig. 6 Changes in root bleeding after heading

and leaf area than those of HY rice, and its source-sink relationship was very coordinated (Lin, 2000). Therefore, the method of strengthening individuals, reducing unproductive tillers and raising the ratio of productive tillers to total tillers and grain-leaf ratio is an effective pathway to achieve SHY rice production.

About 90% of grain-filling materials is from photosynthates after heading (Venkateswarlu and Visperas, 1987),

therefore, increasing grain-filling materials after heading is most important for SHY rice. There are three paths to increase grain-filling materials after heading: the first path is to prolong leaf function period; the second one is to raise the photosynthetic ability per leaf area; and the third is to prolong leaf function period and to raise leaf photosynthetic ability simultaneously. The three paths above are connected with the root system and its vitality (Kang et al., 1992; Zhu et al.,

2000). It is the reason why SHY rice senesced more slowly, and dry matter and filled-grain percentage was higher than that of HY rice. Our experiment demonstrated that the higher root-shoot ratio and larger amount of root exudates of SHY rice relative to HY rice guaranteed the higher dry matter accumulation, higher filled-grain percentage and the slow senescence of the rice plant. Promoting root growth and raising root vitality is another important pathway for SHY rice to obtain high yield.

4.3 Key cultivation techniques for SHY rice

The cultivation techniques for SHY rice have been reported in terms of varietal breeding, nursing of seedlings (Zhao et al., 1995; Ma, 2000; Yang et al., 2003; Jin et al., 2005), planting method and nutrient management. Selecting potentially high yielding varieties, cultivating strong seedlings, wide row and short individual spacing and reasonable fertilizer-water management are all the important techniques for SHY rice. Compared with the conventional SHY cultivation techniques, our experiment made some improvements in the following aspects.

4.3.1 Seedling culture technique with sparse sowing and water control

Seedling bed-field ratio should be raised from 5% to 10% conditioned upon cultivating fertile beds. After removing the plastic film, tension meter was used to monitor the soil water content, and the soil water potential of the seedling bed was kept at the level of -10 to -20 Mpa. Improvement of seedling-bed fertility, thin sowing and water control can make root systems more superior, seedlings stronger and tillers more abundant. This way of cultivation can protect the roots from injury when transplanting and make them more vigorous.

4.3.2 Site-specific N management (SSNM) fertilizing technique

Using the Stanford equation to determine the total fertilizer amount of N, P and K, the amount of top-dressing fertilizer was applied according to SPAD and LCC in the main growth periods (tillering, panicle differentiation and heading) based on the correlation between leaf color (or nitrogen content) and SPAD (or LCC) (the SPAD critical value for applying nitrogen was 39 and LCC was 3.5 in this experiment). SSNM technique was used not only in the cultivation of SHY rice, but also in HY rice cultivation practice in Yangzhou, Wuxi and Lianyungang in Jiangsu Province so that yield could be increased and fertilizers saved significantly (Liu, 2005).

4.3.3 Technique of mid-season moderate draining and alternately irrigating in grain filling periods

Mid-season draining (critical leaf-age for productive tillers) of SHY rice should be earlier than that of HY rice (early

jointing stage), and the mid-season severe draining practiced in the past (water potential of soil was -40 to -50 kpa) should be changed to moderate draining (water potential of soil was -30 kpa). This new water management technique can not only control unproductive tillers, but also prevent rice from growing unsteadily, therefore water-soil relationship, root-shoot relationship and carbon-nitrogen relationship become well coordinated. After the water-sensitive time at anthesis stage, alternate irrigation should be applied in SHY rice, namely to irrigate with shallow water when water potential of soil decreases to -15 to -20 kpa and to irrigate with shallow water again when the soil water potential reached the value. Our experiment showed that alternately irrigation during the grain filling periods can raise root vitality and leaf photosynthesis function, increase matter productivity after heading, and promote the transportation of photosynthates from vegetative organs to grains.

5 Conclusions

Compared with high-yielding rice, SHY rice mainly has the following characteristics: (1) total stems and tillers together with dry matter accumulation were small at early stages, steady at middle stages and high at later stages; (2) the source, sink and flow were characterized by a high photosynthetic potential, high grain-leaf ratio, high matter translocation ratio and high harvest index; (3) the root system had a large root quantity, high root-shoot ratio and strong root vitality; (4) the yield components were characterized by steady and sufficient panicles, more spikelets and high filled-grain percentage.

SHY rice can be realized by enlarging the source, increasing the sink, strengthening the root system and promoting the flow. The cultivation techniques for SHY rice mainly include thin sowing, water control, SSNM fertilizing, mid-season moderate draining and alternately irrigation during the grain filling period.

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