ABSTRACT
Increasing crop yield is a major challenge for modern agriculture. In China hybrid rice has contributed greatly to the self-sufficiency of food supply. To meet the future demand for rice production, a series of national programs on super-rice breeding, functional genomics and GM breeding have been established in China since 1996. We have cloned some important high yield-related genes, IPA1 (Ideal Plant Architecture 1), DEP1(dense and erect panicle 1), GIF1(grain-filling 1), Ghd7(grain weight, plant height and heading date) and GW2(grain width 2). The development of new plant type of IPA, has been proposed as a means to enhance rice yield potential over that of existing high-yield varieties. IPA1, a semidominant quantitative trait locus, profoundly changes rice plant architecture and substantially enhances rice grain yield. IPA1 encodes OsSPL14 (SOUAMOSA PROMOTER BINDING PROTEIN-LIKE 14) and is regulated by microRNA (miRNA) OsmiR156 in vivo. We demonstrate that a point mutation in OsSPL14 perturbs OsmiR156-directed regulation of OsSPL14, generating an ‘ideal’ rice plant with a reduced tiller number, increased lodging resistance and enhanced grain yield. So these yield genes have been used in super-rice and GM breeding to improve rice grain yield. Actual yield of a japonica rice variety XS11-ipa1 could increase 10% over its CK XS11.

KEYWORDS: rice, yield, IPA1 gene, cloning, super-rice breeding

REFERENCES:
High-yield technologies in China

Qian Qian
钱前
China National Rice Research Institute (CNRRI)
2011.11 Japan

Contents
◆ Progress of rice breeding in China
◆ Discovery of yield genes in rice
◆ Breeding strategies for super hybrid rice

Big Question For Big Country
Time: Aug 24, 1994
Person: Americans, Lester Brown
Question: Who will feed China?
Answer: Chinese

Food production must be further improved

1.1 Three stages in rice breeding

- High-yield rice breeding is an eternal theme, getting great achievement in China
- Progress of rice breeding in China
- Discovery of yield genes in rice
- Breeding strategies for super hybrid rice

Green Revolution, 1950's
(2t/ha-4t/ha)
Heterosis, 1970's
(4t/ha-6t/ha)
Super rice research launched in 1996
1.2 Super rice research and ideal-type breeding

High-yield breeding has tended to a plateau, since the dwarf and heterosis breeding have taken two breakthroughs. IRRI launched a new strategy of ideal-type breeding in 1989 and China did the super rice research in 1996. They both achieved some substantive results, but still have a distance away from the break.

- Few tillers (no invalid)
- 200-250 grains/panicle
- Strong stem (90-100 cm)
- Dark green, thick and erect leaves
- Strong root activity
- Growth period of 110-130 d
- Harvest index of 0.6
- Yield potential 13-15 t/ha

1.3 Super rice strategy in China

Three-step strategy:
- 2000: 10.5 t/ha
- 2005: 12 t/ha
- 2015: 13.5 t/ha

Theory and application of Super Hybrid Rice Improvement

- Gene discovery
- Molecular breeding
- Breeding by gene design

1.3 Super rice achievement in China

Rice average yield over 13.5 t/ha in small plot sizes in 2011

1.4 Challenge of rice production and yield in China

The variation tendency of rice planting area and yields in China

Future demand for rice production and yield in China

<table>
<thead>
<tr>
<th>Year</th>
<th>Total output (+10^5 kg)</th>
<th>Increase (%)</th>
<th>Yield (kg/ha)</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>317.5</td>
<td>19.18</td>
<td>6,885</td>
<td>18.3</td>
</tr>
<tr>
<td>2030</td>
<td>247.5</td>
<td>35.62</td>
<td>7,845</td>
<td>32.6</td>
</tr>
</tbody>
</table>

*Estimated based on the per capita paddy rice consumption of 150 kg and the rice cropping area of 31.57 x 10^6 ha; in comparison with 1995.

Chen et al., 2007, JIPB

Contents

- Progress of rice breeding in China
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Rice production demand increased year by year!
2.1 Phenotype of the ipa1 Mutant

A: Phenotype of ipa1 and TN1; B: panicle of ipa1; C: panicle of TN1. Bar, 10 cm.

Functional analysis of IPA1

Confirmation of the OsSPL14 function by overexpressing OsSPL14 in Nipponbare

OsSPL14 is the gene responsible for ideal plant architecture

Phenotypic characterization of NIL OsSPL14/ipa1 plants

Potential applications of IPA1 in rice breeding

Comparison of agricultural traits of NIL OsSPL14/ipa1 plants.

Yield test in a paddy between XS11 and NILXS11 OsSPL14/ipa1 plants

Note: The planting density was 20.98 cm × 23.31 cm, with one plant per hill. The area per plot was 6.67 m². Values are means ± s.d.
2.2 DEP1 (dense and erect panicle-1)

The DEP1 locus was mapped to chromosome 9. The dominant allele at the DEP1 locus is a gain-of-function mutation causing truncation of a phosphatidylethanolamine-binding protein-like domain protein. The effect of this allele is to enhance meristematic activity, resulting in a reduced length of the inflorescence internode, an increased number of grains per panicle and grain yield.

Huang et al., Nat. Genet. 2009

2.3 GW2 (grain width and weight 2)

A new QTL that controls rice grain width and weight. Loss of GW2 function increased cell numbers, resulting in a larger (wider) spikelet hull, and it accelerated the grain milk filling rate, resulting in enhanced grain width, weight and yield.

Song et al., 2007, N.G.

2.4 GIF1 (grain incomplete filling 1)

Grain-filling is an important trait that contributes greatly to grain weight. The rice GIF1 gene that encodes a cell-wall invertase required for carbon partitioning during early grain-filling

Fine mapping with introgression lines revealed that the wild rice GIF1 is responsible for grain weight reduction.

Wang et al., 2008, N.G.

2.5 GS3 (Grain size 3)

The major QTL for grain length and weight and minor QTL for grain width and thickness in rice

GS3 has at least four different alleles according to the coding sequence:
GS3-1 (Zhenshan 97), GS3-2 (Nipponbare), GS3-3 (Minghui 63), GS3-4 (Chuan 7)

Fan et al., 2006, TAG; Mao et al., 2010, PNAS

2.6 Ghd7 (grains per panicle, plant height, heading date)

Ghd7 has played crucial roles for increasing productivity and adaptability of rice globally.

Xue et al., 2008, N.G.

Contents

◆ Progress of rice breeding in China
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3.1 Application of yield genes in rice breeding

*Cultivar: Shengnong265, DEP1 contained*

DEP1 has widely applied in Japonica plant-type breeding in Northern China.

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**Application of IPA1 gene**

IPA1 as a key gene in rice ideal plant type

**Production analysis of single yield gene**

**Production analysis of TWO yield genes**

**Construction of Genotype/Phenotype data pool**

**GP data pool**

**Design target genotypes using 9311 of DEP1, Gn1, MOC1, gwp9**

Table 2 Design target genotypes using 9311

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>YM20/DEP1</th>
<th>YM20/Gn1</th>
<th>YM20/MOC1</th>
<th>YM20/gwp9</th>
<th>YM20/yield (T/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIL-DEP1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>11.2</td>
</tr>
<tr>
<td>NIL-Gn1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>11.2</td>
</tr>
<tr>
<td>NIL-MOC1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>11.0</td>
</tr>
<tr>
<td>NIL-gwp9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NIL-DEP1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>10.0</td>
</tr>
<tr>
<td>NIL-Gn1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>10.5</td>
</tr>
<tr>
<td>NIL-MOC1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>10.5</td>
</tr>
<tr>
<td>NIL-gwp9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Breeding nursery, New breeding lines contains IPA1, CK*

*Production effect analysis of polygenic combination*
3.2 Mid-type restorer of *indica/japonica* is more beneficial to increase yield in super hybrid rice

### Identified some indica-japonica markers related to morphological index

<table>
<thead>
<tr>
<th>Chromosome</th>
<th>RFLP marker (28)</th>
<th>SSR marker (21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RG181, RG245, RG462, RG472</td>
<td>RM22, RM259</td>
</tr>
<tr>
<td>2</td>
<td>RG170, RG256, RG322</td>
<td>RM29, RM280</td>
</tr>
<tr>
<td>3</td>
<td>RG482, RG96</td>
<td>RM16, RM251</td>
</tr>
<tr>
<td>4</td>
<td>RG214, RG286</td>
<td>RM226</td>
</tr>
<tr>
<td>5</td>
<td>RG287, RG474</td>
<td>RM13</td>
</tr>
<tr>
<td>6</td>
<td>RG64, RM928</td>
<td>RM17</td>
</tr>
<tr>
<td>7</td>
<td>RG251, RG551</td>
<td>RM18, RM224, RM248</td>
</tr>
<tr>
<td>8</td>
<td>RG379, RG562</td>
<td>RM25</td>
</tr>
<tr>
<td>9</td>
<td>RG555, RG570, RG697</td>
<td>RM245, RM280</td>
</tr>
<tr>
<td>10</td>
<td>RG752, RG911</td>
<td>RM228, RM282</td>
</tr>
<tr>
<td>11</td>
<td>RG167</td>
<td>RM282</td>
</tr>
<tr>
<td>12</td>
<td>RG61, RG343, RG758</td>
<td>RM4, RM220, RM247</td>
</tr>
</tbody>
</table>

### Using marker RG345 to check DH of indica/japonica

**Note:**
- Marker: A/HindIII, 2/TaeII: 3.02428; 4-5 and 8-10, Indica cultivars;
- 6-7, Japonica cultivars; 11-21, Lines of DH population

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![Pyramid Breeding and application of high-yield lines](image1)

![Model of Super Rice in the Future](image2)

![Development of medium type restore lines in subspecies differentiation](image3)

![Identified some indica-japonica markers related to morphological index](image4)

![Using marker RG345 to check DH of indica/japonica](image5)
Coefficient between markers and morphological index

<table>
<thead>
<tr>
<th>Canonical variable</th>
<th>canonical correlation coefficient</th>
<th>$\chi^2$</th>
<th>Degree of freedom</th>
<th>significant level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8744</td>
<td>399.02</td>
<td>162</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>0.7255</td>
<td>249.82</td>
<td>130</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.6629</td>
<td>171.83</td>
<td>100</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>4</td>
<td>0.5909</td>
<td>112.81</td>
<td>72</td>
<td>0.002</td>
</tr>
<tr>
<td>5</td>
<td>0.5727</td>
<td>65.98</td>
<td>46</td>
<td>0.014</td>
</tr>
<tr>
<td>6</td>
<td>0.5180</td>
<td>36.31</td>
<td>22</td>
<td>0.111</td>
</tr>
<tr>
<td>7</td>
<td>0.0002</td>
<td>-1.8E-06</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Relationship between subspecies differentiation index of the paternal parents and grain yield per plant of their F1 hybrids

Improvement strategy for mid-type restorers

- To breed mid-type restorer using multi-backcross between indica and japonica.
- Morph-index: 12-16, japonica marker index: 0.3-0.6.
- Successfully gained restorers: Zhonghui8006 and Zhonghui111, their marker index: 0.25 and 0.39.

Excellent restorer Zhonghui8006

- New variety protection NA001233E
- Variety certification:
  - Guodao1 (Zhong9A/Zhonghui8006)
  - Guodao3 (Zhong8A/Zhonghui8006)
  - II-you8006 (B.32A/Zhonghui8006)
  - Guodao6 (Neixiang2A/Zhonghui8006)
  - Tianyou6 (Tianfeng4/Zhonghui8006)

Super rice restorer with multi-genes

<table>
<thead>
<tr>
<th>Restorer</th>
<th>Heading date/d</th>
<th>Spikelet per panicle</th>
<th>Settling percentage/</th>
<th>1000-grain weight</th>
<th>Genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhonghui8006</td>
<td>90</td>
<td>176</td>
<td>84</td>
<td>27</td>
<td>Xa4+xa5+xa13+Xa21</td>
</tr>
<tr>
<td>Zhonghui111</td>
<td>87</td>
<td>178</td>
<td>87</td>
<td>27</td>
<td>xa5+Xa21+P25</td>
</tr>
<tr>
<td>Zhonghui8015</td>
<td>90</td>
<td>154</td>
<td>89</td>
<td>31</td>
<td>P25+Xa21</td>
</tr>
<tr>
<td>Zhonghui161</td>
<td>92</td>
<td>163</td>
<td>88</td>
<td>26</td>
<td>Pib+Pita+Xa4+xa13+Xa21</td>
</tr>
<tr>
<td>Zhonghui14</td>
<td>130</td>
<td>138</td>
<td>77.1</td>
<td>21</td>
<td>xa5+P25+Pph15</td>
</tr>
<tr>
<td>Zhongju A</td>
<td>66</td>
<td>97</td>
<td>0</td>
<td>24</td>
<td>xa5+Xa23</td>
</tr>
<tr>
<td>Zhongju 2A</td>
<td>76</td>
<td>103</td>
<td>0</td>
<td>25</td>
<td>P21+P22+Pb33</td>
</tr>
<tr>
<td>Zhongjiazao17</td>
<td>85</td>
<td>125</td>
<td>90</td>
<td>27</td>
<td>xa5+P25</td>
</tr>
<tr>
<td>Zhonghui333</td>
<td>90</td>
<td>145</td>
<td>87</td>
<td>26</td>
<td>Xa4+Xa21</td>
</tr>
</tbody>
</table>
Medium type restorer line R9308 and its super hybrid Xieyou 9308

Field performance of Xieyou 9308 with harmonious plant type, in Xinchang, Zhejiang Province, China

Guodao 6

Conclusion

◆ Great success on rice production was achieved via semi-dwarf breeding, Heterosis utilization and super rice project.
◆ A series of rice germplasm and yield genes, IPA1, DEP1, have been discovered and cloned.
◆ New breeding strategies, including breeding by gene design, pyramiding breeding and mid-type restorer selection, has been used in super hybrid rice breeding

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