Introduction

Rice (Oryza sativa) is one of the most important crops in the world. In China, its culture area accounts for about 25% of the whole cereal culture area, and accounted for about 50% of total food supply in 2010. Excellent rice cultivars are essential to increase field yields and improve rice taste and cooking quality. The application of high quality seeds contributes to about 70% efficiency of total improvement methods (Cheng et al. 2007, Maninder et al. 2015). To produce excellent rice cultivars with high yield, high resistance to disease and insects, outstanding quality, and adaptation to a wide range of ecological niches are the goals of rice breeders (Khush 2001, Xing and Zhang 2010).

Traditional rice breeding procedures include several generations of crossing and backcrossing between two parental cultivars to combine and stabilize desired agricultural traits (Giri and Vijaya Laxmi 2000). Seven to eight generations are required from the start of crossing to final authorization, and more generations are necessary for distant hybridization. Medium-late Japonica rice, which covers the most culture area in China, can only be cultured one generation in its local area because of its high-sensitive to light, two generations could be accomplished in a year with one more generation in the tropical area. With normal breeding procedures and natural conditions in China, it always takes researchers five or more years to complete these tedious processes of crossing and selection. This long breeding period greatly decreases the efficiency of research and development of new varieties. Therefore, methods for fast culturing are in urgent need. Rice is an annual, warm, short-day crop, growing in environments with high temperature and high humidity (Sweeney and McCouch 2007). Rice is divided into two major subspecies, Indica rice and Japonica rice. Indica rice is tolerant to high temperature and strong light; in contrast, Japonica rice is tolerant to low temperature and weak light strength (Kovach et al. 2007, Sang and Ge 2007). Based on differences in response to light period, rice can be classified into early, medium, and late types (Wei et
The late types are light-sensitive and flower only in short-day conditions, whereas the early and medium types are less sensitive to light and show no significant response to light-period changes. The growth period of rice is restricted by both light and temperature: it grows and develops faster under high temperature, while heading earlier under short-day conditions with enough vegetation growth. Therefore, an accelerated rice culturing method can be developed according to growth habits in terms of light and temperature.

Hainan Province (the southernmost province of China) is located between 18 and 20 degrees north latitude and has sufficient light and temperature sources for rice growth throughout the year (Gao et al. 2014). From September to the following May (the autumn, winter and spring seasons of the Northern Hemisphere), the light condition at Hainan Province is in short-day period, which induces rice to flower much earlier than that of normal growing time (from April to October) in Zhejiang Province (located in the semitropical region of China) (http://www.weather.com.cn/html/weather/101210301.shtml). Taking advantage of the short days and high temperature climate in Hainan Province, we performed some simple manipulations, which we have termed the “1 + 2”, “2 + 2”, “1 + 3”, and “0 + 5” methods, to shorten rice life cycle to about 70–80 days. For the “1 + 2” and “2 + 2” methods, 2 generations were completed in Hainan Province and 1 or 2 generations in Zhejiang Province. For the “1 + 3” method, we cultured rice for 1 generation in Zhejiang Province and 3 generations in Hainan Province. For the “0 + 5” method, we cultured rice for 5 generations in Hainan Province with no breeding in Zhejiang Province. With these breeding methods, we cultured rice for four to five generations in one year, which observably promoted the breeding process. This practical proposal for shorting the rice breeding process could be used for reference in other areas located in temperate zones and semitropical areas, to increase generations of rice breeding.

Materials and Methods

Materials and growth conditions

To obtain general data of rice life cycle, twenty widely applied cultivars were chosen to represent four classificatory types, i.e., early Indica, medium Indica, medium Japonica, and late Japonica. Some of them are traditional cultivars and some are hybrid rice varieties or restored lines from different culturing regions of China or other countries (Supplemental Table 1). All varieties were cultured both in Jiaxing and Lingshui. Jiaxing, located in southeast China, has a typical semitropical climate, while Lingshui (in Hainan Province) stands in the southernmost area of China with a typical tropical climate (Supplemental Fig. 1, http://ditu.google.cn/maps).

Culture arrangement for different purposes

For cultivars whose yields and growth characteristics in Jiaxing needed to be determined, we planted them in Jiaxing to complete one generation from late May to late October. We then cultured them in Lingshui from October to the following May to complete another three generations. For plants used for genetic analysis, construction of a mapping population, making a recombinant inbred line (RIL), or continuous backcrossing, we planted them only in Lingshui to complete five generations in one year. Detailed manipulations are described in the following paragraphs.

Technique I: direct planting and subsequent culturing

To reduce wounding of seedlings during transplanting, all seedlings were directly planted in the field, without additional processes of culturing seedlings in a nursery and further transferring them to another place (Fig. 1D, 1E, 1F). To culture small samples, we planted germinated seeds in an 8 cm × 8 cm line-to-row ratio (36 seedlings) in a 50 cm × 50 cm square. For larger samples, we expanded the field to 90 cm × 90 cm to plant about 150 seedlings. A wood board was used to cover seedlings with mud. Irrigation and fertilization of seedlings were performed after the 3rd leaf appeared. Other field management was conducted in a normal manner.

Fig. 1. Manipulations to shorten rice life cycle in Lingshui. A. Cutting half of the glumes of impregnated flowers. B. Unpolished seeds resulting from crossing. C. Unpolished seeds resulting from cutting the top 1/3 of glumes of male parent. D. Whole spikes with germinating seeds. E. Direct planting of whole spikes with germinating seeds. F. Direct planting of individual samples.
Technique II: crossing method

When rice opens flowers, choose inflorescences with some opened flowers from strong tillers to cross or backcross. Remove the opened flowers and left about 25 impreg-nate flowers for each tiller in the afternoon, when the opened flowers close its glume two hours later. Then cut the top half of glumes to remove stamens with covering by envelopes (Fig. 1A). On the next day, pollination was performed with pollen from a different background. The crossing seeds were harvested (Fig. 1B) 15–18 days after pollination. For male-sterile lines which do not require artificial emasculation, the manipulations are the same as traditional rice crossing without removing stamens.

Technique III: treatment for promoting maturation

Firstly, rice was planted at a proper high density (90–100 plants/m²). Seeding density is an important factor for rice yield (Lin et al. 2011, Wang et al. 2014). In our experi-ence, high density seedlings can also promote rice matura-tion: growing rice seedlings at a proper high density always leads to the mimicking of a short-day effect, and direct planting associated with rational close planting can promote rice to flower earlier by 10–15 days than transplanting rice.

Secondly, the glumes were cut at rice florescence. Ac-cording to our experience, hybrid seeds have germination ability 15 days after pollination. To make the maturation stage of parental plants consistent with hybrid rice, flowers at the lower part of the spike were removed, leaving several strong spikelets, and the top 1/3 of glumes were cut to pro-mote maturing of male parent, which provides pollen in the next generation (Fig. 1C).

Thirdly, artificial short-day conditions were made to ac-celerate maturation. Day length plays an important role for late Japonica rice florescence (Ghose and Shastry 1954, Song and Luan 2012). There are long-day light conditions in Lingshui (from late April to late July) and Jiaxing (from March to early August). Light-sensitive cultivars will stay in the vegetative stage without growth-phase transition. To ac-celerate the early maturation of these cultivars, we placed artificial shades on rice seedlings at a growth stage of more than five leaves old. Using black plastic woven mesh to cover them at 5 p.m. and uncovering the mesh at 7 a.m. on the next morning resulted in 11 : 13 h of light: dark photo-period. This treatment was performed continuously for about 14 days.

Technique IV: dormancy breaking and germination treatment

The freshly harvested seeds were treated with desiccation-HNO₃ treatment-germination acceleration to break seed dormancy and germination (Bewley 2013, Bradbeer 1988, Zhang et al. 2009). The unpolished seeds or the whole spikes were desiccated at 50°C for 24–30 hours in a drier. They were then subjected to HNO₃ solution treatment for 58–60 hours to thoroughly break dormancy. These seeds were washed with clear water and put in an incubator for germination for 40–50 hours. When 70% of the seeds were germinated, seedlings were properly transferred to the field to prevent their roots from growing too long to separate from each other (Fig. 1C). To make the HNO₃ solution, we added 3.5 ml 36% HNO₃ (Sinapharm, China) to 1 L water for grains while adding 2.5 ml 36% HNO₃ to 1 L water for unpolished seeds. The HNO₃ solution should be newly made to prevent HNO₃ volatilization.

Results

Determination of rice life cycles

From 2001 to 2011, we observed and determined the growth and development characteristics of more than 20 Indica and Japonica varieties in Jiaxing and Lingshui. Nor-mally, rice can grow two generations from mid-April to late October in Jiaxing, with a lifespan of about 95 (early Indica rice) and 155 (late Japonica rice) days for each generation. As shown in Table 1, the life cycle of early Indica and late Japonica is about 70 days in the autumn and spring seasons in Lingshui, which is remarkably shorter than that in Jiaxing in the summer season. Interestingly, the life cycle of these cultivars in the autumn and spring seasons is much shorter than that in the winter season (about 100 days), correspond-ing to low-temperature conditions of Lingshui in the winter. On the other hand, some cultivars of medium Indica and Japonica (such as BG367-4, IR54, and Minghui63) have a long basic vegetative growth period (more than 115 days for each generation) in both places. Therefore, it is difficult to use this protocol to shorten their life cycle. To obtain repeat-able and reliable results, we recorded related light and tem-perature parameters for every breeding generation (data not shown).

Effectiveness of the treatments for shortening rice life cycles

To evaluate the effectiveness of treatments for shortening rice life cycles, two late Japonica rice varieties, ‘Jia58’ and ‘Jia33’, were planted in Jiaxing and Hainan between 2012 and 2013.

The ‘Jia33’ was planted in Hainan for two generations between 11/25/2012 and 05/18/2013; the high-density direct seeding method (90–100 plants/m²) and normal seeding method (transplanting at a density of 30–37 plants/m²) were used for comparison. The results indicated that 12 and 14 days of the rice life cycles were shortened with the high-density direct seeding method (Table 4). The ‘Jia58’ and ‘Jia33’ planted with the normal seeding method were used to compare the effectiveness of cutting glumes. ‘Jia33 × Jia58’ crossing was also carried out to compare the matura-tion process of hybridization seeds and normal seeds. The results showed that the growth period from flowering to maturation could be shortened to about 15 days, and short-ened to 12 days using unpolished rice for germination (Table 5). The results also indicated that the growth period showed no significant difference between flowers with or
without artificial pollination after cutting glumes.

The artificial short-day conditions could accelerate the early maturation of light-sensitive cultivars. We placed artificial shades on rice seedlings at a growth stage of more than five leaves old for about 14 days. With this treatment, the rice growth period was shortened to about 50 days, and life cycles could be completed in 100–110 days (Table 6).

As freshly harvested rice seeds remain dormant, breaking dormancy treatment, such as H2O2, GA3, KNO3, or HNO3, should be applied to accelerate rice breeding (Lei et al. 2004, Zhang et al. 2009). Low content of HNO3 solution was used to break dormancy in this protocol. The germination percentage reached about 85% after 5 days of acceleration, while 15 days will be needed by the contrast (Fig. 2).

**Table 1. Life cycle record of varieties in different seasons in Jiaxing and Lingshui. 2001–2011**

| # | Cultivar name      | Summer season in Jiaxing (April to Oct.)* | Autumn season in Lingshui (Sep. to Dec.) | Winter season in Lingshui (Dec. to March) | Spring season in Lingshui (Feb. to May) | Early summer season in Lingshui (March to June) |
|---|--------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| 1 | Jiaying aromatic rice | 95 ± 5                                   | 80 ± 5                                   | 90 ± 5                                   | 75 ± 5                                   | 70 ± 5                                   |
| 2 | Jiaxing8            | 90 ± 5                                   | 80 ± 5                                   | 90 ± 5                                   | 75 ± 5                                   | 69 ± 5                                   |
| 3 | Jiashao1            | 90 ± 5                                   | 75 ± 5                                   | 85 ± 5                                   | 72 ± 5                                   | 68 ± 5                                   |
| 4 | Jiayu293            | 93 ± 5                                   | 80 ± 5                                   | 90 ± 5                                   | 75 ± 5                                   | 70 ± 5                                   |
| 5 | Xieqingzao          | 100 ± 5                                  | 85 ± 5                                   | 100 ± 5                                  | 80 ± 5                                   | 75 ± 5                                   |
| 6 | Minghuai63          | 125 ± 5                                  | 95 ± 5                                   | 110 ± 5                                  | 100 ± 5                                  | 90 ± 5                                   |
| 7 | Pei lai64s          | 115 ± 5                                  | 90 ± 5                                   | 100 ± 5                                  | 95 ± 5                                   | 85 ± 5                                   |
| 8 | Lemont              | 112 ± 5                                  | 96 ± 5                                   | 105 ± 5                                  | 99 ± 5                                   | 86 ± 5                                   |
| 9 | Rico No 1           | 110 ± 5                                  | 95 ± 5                                   | 105 ± 5                                  | 97 ± 5                                   | 88 ± 5                                   |
| 10| Jiuxian hui82       | 125 ± 5                                  | 98 ± 5                                   | 118 ± 5                                  | 100 ± 5                                  | 90 ± 5                                   |
| 11| Zhendaoo88          | 130 ± 5                                  | 81 ± 5                                   | 91 ± 5                                   | 72 ± 5                                   | 70 ± 5                                   |
| 12| Jiuhui47            | 130 ± 5                                  | 80 ± 5                                   | 92 ± 5                                   | 70 ± 5                                   | 70 ± 5                                   |
| 13| Jiuhui67            | 120 ± 5                                  | 85 ± 5                                   | 97 ± 5                                   | 70 ± 5                                   | 73 ± 5                                   |
| 14| Liangjing9          | 110 ± 5                                  | 70 ± 5                                   | 87 ± 5                                   | 70 ± 5                                   | 70 ± 5                                   |
| 15| Koshihikari         | 105 ± 5                                  | 75 ± 5                                   | 95 ± 5                                   | 75 ± 5                                   | 76 ± 5                                   |
| 16| Wayujing7           | 140 ± 5                                  | 81 ± 5                                   | 105 ± 5                                  | 80 ± 5                                   | 76 ± 5                                   |
| 17| Jia06-64            | 155 ± 5                                  | 97 ± 5                                   | 100 ± 5                                  | 95 ± 5                                   | 76 ± 5                                   |
| 18| Jia33               | 155 ± 5                                  | 80 ± 5                                   | 95 ± 5                                   | 75 ± 5                                   | 75 ± 5                                   |
| 19| Jiayou2             | 150 ± 5                                  | 78 ± 5                                   | 92 ± 5                                   | 75 ± 5                                   | 76 ± 5                                   |
| 20| 5088s               | 150 ± 5                                  | 80 ± 5                                   | 92 ± 5                                   | 75 ± 5                                   | 73 ± 5                                   |

1–10 were Indica cultivars, whose data were the average over four years from 1996 to 1999. 11–20 are Japonica cultivars, whose data were the average over four years from 2006 to 2009.

*: In Jiaxing, Indica cultivars were planted in the middle ten days of April while Japonica cultivars were planted in the last ten days of May.

The artificial short-day conditions could accelerate the early maturation of light-sensitive cultivars. We placed artificial shades on rice seedlings at a growth stage of more than five leaves old for about 14 days. With this treatment, the rice growth period was shortened to about 50 days, and life cycles could be completed in 100–110 days (Table 6). As freshly harvested rice seeds remain dormant, breaking dormancy treatment, such as H2O2, GA3, KNO3, or HNO3, should be applied to accelerate rice breeding (Lei et al. 2004, Zhang et al. 2009). Low content of HNO3 solution was used to break dormancy in this protocol. The germination percentage reached about 85% after 5 days of acceleration, while 15 days will be needed by the contrast (Fig. 2).

### Culture arrangement and application examples

Taking advantage of the treatments for shortening rice life cycles, while considering breeding purpose, we proposed four methods which we have termed “1 + 2”, “2 + 2”, “1 + 3”, and “0 + 5”. Detailed operation methods and application examples are as follows.

**“1 + 2” and “2 + 2” methods for two generations in tropical regions**

The “1 + 2” method is suitable for Japonica rice varieties from the Huang-huai-hai region and the northeast area of China with a life cycle of more than 150 days. The “2 + 2” protocol is suitable for double-cropping early Indica rice from the middle and lower regions of the Yangtze River. After complete production in its original region, two generations were cultured in a tropical region from early October to late March. For the first generation, seeding at early October and harvest at mid-December; From late December to late March for the second generation.

Take the breeding of “Shaojia1” which is an early Indica rice for example. The F2 group named “199706” was planted by direct seeding in Lingshui on October 20, 1997; 113 spikes with desirable agronomic characteristics were selected on January 3, 1998. The 113 spikes, named “F3-1–113”, were divided into two groups, one for direct seeding on January 11, and the other for rice blast resistance detection. On April 7, 71 of 113 spikes with good agronomic characteristics and...
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**Table 2.** The construction process of “Jiahui30” IP A1 near-isogenic line

| Generation | Area          | Seeding date (month/day/year) | Materials                  | Crossing date (month/day/year) | Manipulation                        |
|------------|---------------|-----------------------------|---------------------------|--------------------------------|-------------------------------------|
| 1          | Lingshui      | 12/25/2010                 | e6 and JH30               | 2/12/2011                      | e6 × JH30                           |
| 2          | Lingshui      | 3/6/2011                   | F1 and JH30               | 4/26/2011                      | F1 × JH30                           |
| 3*         | Jiaxing       | 5/25/2011                  | BC1F1 and JH30            | 8/1/2011                       | BC1F1 × JH30                        |
| 4          | Lingshui      | 8/30/2011                  | BC2F2 and JH30            | 10/14/2011                     | BC2F2 × JH30                        |
| 5          | Lingshui      | 11/8/2011                  | BC3F3 and JH30            | 1/23/2012                      | BC3F3 × JH30                        |
| 6          | Lingshui      | 2/20/2012                 | BC4F4                     |                               | BC4F4                               |
| 7          | Jiaxing       | 5/25/2012                  | BC5F5                     |                               | BC5F5                               |
| 8          | Lingshui      | 9/30/2012                  | J335A, J60A, J57 and BC4F3| 11/15/2012                     | J335A, J60A, J57 × BC4F3 separately |
| 9          | Lingshui      | 12/10/2012                 | 3 hybrid combinations    |                               | Hybrid rice test and regional test  |

* The IP A1 gene was tested in every generations from BC1F1 to “Jiahui30” NIL completed.

**Table 3.** The construction process of “Jia33” near-isogenic line

| Generation (address) | Seeding date (month/day) | Materials | Heading date (month/day) | Manipulation | Harvest date (month/day) | Remarks | Growth period (days) |
|----------------------|--------------------------|-----------|--------------------------|--------------|--------------------------|---------|----------------------|
| 1 (Jiaxing)          | 5/25                     | P1 (Jia64) and P2 (Jia33) | 8/25 | P1 × P2 | 9/15 | Harvest F1 seeds | 114 |
| 2 (Hainan)           | 9/22                     | F1        | 11/8 | Select 250 spikelets, cutting top glume | 11/24 | Harvest 189 F2 seeds | 64 |
| 3* (Hainan)          | 11/28                    | F2 and P2 | 1/26 | Glabrous Plant × P2 | 2/15 | Harvest B1F1 27 seeds | 80 |
| 4 (Hainan)           | 2/20                     | B1F1      | 4/6 | Select 300 spikelets of different plants, cutting top glume | 4/25 | Harvest B1F2 281 seeds | 65 |
| 5 (Hainan)           | 4/28                     | B1F2 and P2 | 6/16 | Short-day treatment for 12 days on 5/14, Select Glabrous Plant × P2 | 7/5 | Harvest B2F2 seeds | 69 |
| 6 (Hainan)           | 7/9                      | B2F3      | 8/26 | Select 300 spikelets of different plants, cutting top glume | 9/13 | Harvest B2F2 seeds | 67 |

* The third generation in Hainan was planted in a plastic greenhouse to promote rice growth.

Based on the records of life cycle of different cultivars in Jiaxing and Lingshui from 1996 to 2014, we developed a fast rice culturing protocol for breeding. This protocol combines four major manipulations to shorten the rice life cycle.
to about 70 days. This fast-breeding protocol can be applied in genetic analysis, construction of mapping populations and near-isogenic lines (NIL), and continuous crossing and backcrossing in breeding procedures. With this protocol, we have generated six authorized cultivars in only three years, which is much faster than the average efficiency of new cultivar development.

The fast-breeding protocol was developed according to rice growth characteristics, mainly on the short-day feature. The rice flowering phase is controlled by a number of environmental factors, such as day length, temperature, and water supply. Day length plays an important role in flowering time for late Japonica rice of the strong light-sensitive type (Ghose and Shastry 1954, Song and Luan 2012). The artificial short-day conditions could be manipulated in two ways, one by shading with black plastic woven mesh at the five-leaf-old growth stage, and the other by high-density direct seeding. We found different treating days should be applied to different growth stages, 14 days for five-leaf-old seedlings, 12 days for seven-leaf-old seedlings, and 10 days for nine-leaf-old seedlings (Li et al. 2014). However, a higher density (90–100 plants/m²) has been suggested in order to create short-day conditions and speed up the breeding process. Light-sensitive rice always shows ‘over-optimum age’ phenotype and heads earlier under short-day conditions. In this study, we were able to head rice 10–15 days earlier by high-density direct seeding.

In our experience, cutting glumes can promote maturation. Self-fertilization seeds can have germination ability at 15 days after cutting the top 1/3 of glumes, which seems like hybrid seed, because only strong spikelets were left and more nutrients could be used for seed development. It will take more than 30 days from flowering to maturation for inflorescence without treatment. Thus, a reduction of 10–15 days can be achieved using unpolished rice for germination. Freshly harvested rice seeds remain dormant, but it has been reported that many methods can be used to break seed dormancy, such as chilling, dry storage, light, and exposure to chemicals. (Bewley 2013, Bradbeer 1988). H₂O₂, GA₃, KNO₃, and HNO₃ have been reported to be effective chemicals in breaking rice dormancy (Lei et al. 2004, Zhang et al. 2009). Rice can reach an 88% seed germination rate after 24 h of soaking in 0.5% HNO₃ solution (Zhang et al. 2009). In this study, we proposed two concentrations of HNO₃ solution for grains and unpolished seeds. The seed germination rate could reach about 85% after 5 days of germination treatment. Therefore, HNO₃ solution treatment can be an effective method to break seed dormancy.

From 1993 to 2013, we successfully bred 18 new varieties and 4 male-sterile lines. Fifteen varieties were characterized in one province, and 3 varieties were authorized in more than two provinces or were authorized by state organizations (Supplemental Table 2). During our early stage (1993–2003), we only generated 4 traditional rice cultivars, without any hybrid rice or male-sterile line. The average

Table 4. Effectiveness of high-density direct seeding

| Planting address | Material | Seeding date (month/day/year) | Heading date (month/day/year) | Maturation date (month/day/year) | Growth period (days) |
|------------------|----------|-------------------------------|-------------------------------|---------------------------------|---------------------|
| Hainan           | Jia33    | 11/25/2012                    | 02/04/2013                    | 03/01/2013                      | 95                  |
| Hainan           | Jia33    | 11/25/2012                    | 01/23/2013                    | 02/16/2013                      | 83                  |
| Hainan           | Jia33    | 03/01/2013                    | 04/26/2013                    | 05/18/2013                      | 79                  |
| Hainan           | Jia33    | 03/01/2013                    | 04/14/2013                    | 05/04/2013                      | 65                  |

Table 5. Effectiveness of cutting glumes

| Planting address | Material | Glume treatment | Crossing date (month/day/year) | Flowering date (month/day/year) | Maturation date (month/day/year) | Growth period from flowering to maturation (days) |
|------------------|----------|----------------|-------------------------------|-------------------------------|---------------------------------|-----------------------------------------------|
| Hainan           | Jia33    | Cutting glumes | –                             | 04/30/2013                    | 05/15/2013                      | 15                                            |
| Hainan           | Jia58    | Cutting glumes | –                             | 04/30/2013                    | 05/16/2013                      | 16                                            |
| Hainan           | Jia33    | Cutting glumes | Jia33 × Jia58                 | 04/30/2013                    | 05/13/2013                      | 13                                            |
| Hainan           | Jia33    | Without treatment| –                             | 04/30/2013                    | 05/30/2013                      | 30                                            |
| Hainan           | Jia58    | Without treatment| –                             | 04/30/2013                    | 05/31/2013                      | 31                                            |

Table 6. Effectiveness of artificial short-day conditions

| Planting address | Material | Seeding date (month/day/year) | Short-day treatment starting date (month/day/year) | Short-day treatment ending date (month/day/year) | Maturation date (month/day/year) | Growth period (days) |
|------------------|----------|-------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------|---------------------|
| Jiaxing          | Jia58    | 5/25/2013                      | –                                               | –                                               | 11/01/2013                    | 160                 |
| Jiaxing          | Jia58    | 5/25/2013                      | 6/29/2013                                       | 7/13/2013                                       | 8/26/2013                     | 93                  |
| Jiaxing          | Jia33    | 5/25/2013                      | –                                               | –                                               | 10/28/2013                    | 156                 |
| Jiaxing          | Jia33    | 5/25/2013                      | 6/27/2013                                       | 7/11/2013                                       | 8/23/2013                     | 90                  |
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time consumed for each cultivar was more than 5 years, and the total culturing area was no more than 100,000 hectares. However, after we gradually developed this method for multiple-generation breeding and adopted it from 2003, 14 cultivars were generated and characterized. More remarkably, we developed 8 new varieties within only four years from 2007 to 2010. Two of these outstanding varieties, “Jia58” (authorized in Zhejiang) and “Jia33” (authorized in Jiangsu, Zhejiang, and Shanghai) have been planted for more than 335,000 hectares. These new varieties not only display excellent quality, high yield, and high resistance to various kinds of pathogens, but also are suitable for planting under different climate conditions and environments in China. Recently, we adopted this protocol to introduce the Japonica variety to Jiangxi local varieties and successfully obtained two lines showing remarkable high field production within 18 months (unpublished data). Thus, this fast culturing protocol has shown great advantage in improving current breeding courses and procedures and has brought much benefit to modern agriculture production.

Arabidopsis is adopted as a model organism in a wide range of theory and application studies, owing to its small size, simple genome, multiple genetic resources, and especially, for its fast growth speed (Arabidopsis: a laboratory manual, 2002). In a typical greenhouse with long-day conditions, Arabidopsis completes its life cycle in about two months; thus, it can reproduce more than 6 generations in one year (Arabidopsis: a laboratory manual, 2002; Li et al., unpublished data). As Arabidopsis grows fast, researchers can easily and quickly obtain genetic analysis data, construct mapping populations, gain homozygote transgenic plants, and make double or even higher multiple mutants. Rice has been adopted as a model organism for its absolute importance in the global food supply (Cheng et al. 2007). Originally, rice was a short-day organism with a long basic vegetative growth period; the life cycle of most rice varieties is more than 120 days, and even 160 days. The biggest obstacle in conducting genetic analysis or breeding studies on rice is its long period of growth and development. To accelerate the breeding process, breeding researchers have to culture rice one generation in a native region and one generation in winter in a tropical region (e.g., Hainan in the south of China). With this protocol, we have greatly shortened the rice life cycle to about 70 days, which is comparable to that of Arabidopsis. We can arrange rice experiments or breeding procedures that are the same as those for Arabidopsis, which remarkably increases our efficiency in development of new cultivars. This protocol is suitable for not only light-sensitive varieties or those having a short basic vegetative growth period from East Asia but also early Indica cultivars from South China. For varieties displaying a long basic vegetative growth period, such as late maturing medium Japonica and late maturing medium Indica from South China or Southeast Asia, this protocol cannot evidently promote their growth. In addition, this protocol will also provide some clues to the promotion of breeding processes of other light-sensitive organisms, such as maize and soybean.

Furthermore, cultivars developed with this protocol show enhanced light sensitivity, high-temperature tolerance, and a little earlier maturation than other varieties generated in native regions (Li et al., unpublished data). These excellent characteristics provide two important advantages. First, those cultivars showing less light sensitivity can complete their life cycle before the cold wave comes and grow well in an even higher temperature climate, leading to stable high yields and wider applications from north China to south China. Second, the flowering date of these cultivars is steady and the flowering times of restored lines and male-sterile lines can coincide properly, which will greatly increase the production of hybrid seeds of rice.

In applying this protocol, we advise noting the following additional points. First, researchers should choose appropriate and fertile fields with good irrigation. Second, to prevent the interference of previous rice seedlings growing in the same field, other crops or vegetables should be cultured before planting rice. Third, as the roots of directly planted rice grow on the soil surface, irrigation and fertilization should be managed properly. Finally, high-density direct seeding should be of proper density (90–100 plants/m²), or the plants will be too weak and easily falling by seeding too close.

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