Rice (Oryza sativa L.) is the staple food for more than half of the world's population (Muthayya et al., 2014). China is a major rice-producing country, accounting for about 30% of the global rice production (World Rice Statistics database; IRRI, 2018). Rice yield has more than tripled over the past several decades in China due to the development of new cultivars, such as semidwarf cultivars in the late 1950s and hybrid rice cultivars in the late 1970s, and improved crop management practices such as fertilization and irrigation (Peng et al., 2009). These technical advances in rice production in China have undoubtedly been important for world food security.

Although increasing yield has been, and probably will continue to be, the chief objective in rice production, improving yield stability (i.e., the ability of a crop to maintain yield performance across diverse environments and multiple years) is also a goal of agricultural progress (Slafer and Kernich, 1996; Calderini and Slafer, 1998; Rakshit et al., 2014). Improving yield stability has become even more important because our climate is changing and the intensity and frequency of extreme weather events may increase in the future (Rosenzweig et al., 2001; Qiu, 2010; Zhang et al., 2014). However, our knowledge regarding how rice yield stability has changed in China is still rather limited.

Southern China plays a critical role in China's national rice production, comprising about 80% of the national rice harvested area (IRRI, 2018). Rice yield data during a 67-yr period for 12 provinces in southern China (Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan, and Zhejiang) were collected from the World Rice Statistics database (from 1949 to 2013) and the database of the National Bureau of Statistics of China (for 2014 and 2015). Relative yield residuals for each province were calculated and indicated that rice yield stability significantly increased in 10 of the 12 provinces, with only Guangdong and Guizhou not showing an increase during this 67-yr period. We believe that a stable increase in rice production is achievable in southern China with the continuous efforts to develop new cultivars, improve crop management practices, and strengthen public services such as releasing disaster information and using technical experts.

Materials and Methods

Twelve provinces in southern China were included in this study (Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan, and Zhejiang). Rice yield data from each province during the
period 1949 to 2015 were collected from the World Rice Statistics database (1949–2013; IRRI, 2018) and the database of the National Bureau of Statistics of China (2018) for the years 2014 and 2015. We used this period based on the current availability of data. Data for the number of hybrid and inbred cultivars released in the 12 provinces during the same period were collected from the China Rice Data Center (2018).

Relative yield residuals were calculated from regression analysis between grain yield and year (i.e., the difference between actual and predicted data, presented as a percentage of actual compared with predicted data). These were used for assessing time trends in the change of yield stability (Calderini and Slafer, 1998). A decreased trend in the relative yield residuals indicates an increased trend in yield stability, and vice versa. Grain yields were regressed against years using linear regression for each province (Fig. 1). The regression model was $y = a + bx$, where $y$ stands for the grain yield, $a$ the intercept, $b$ the rate of yield gain, and $x$ the year. The significance of time trends in change of the relative yield residuals was determined by testing the statistical significance of the slope at the $P < 0.05$ probability level according to the Student’s $t$ test (Statistix 8.0, Analytical Software, Tallahassee, FL).

**Results and Discussion**

Rice yields were linearly increased in all the 12 provinces from 1949 to 2015 (Fig. 1). However, the yield increase rates (slopes of regression lines) were different among provinces. The highest yield increase rate was recorded in Jiangsu (0.114 t ha$^{-1}$ yr$^{-1}$), and the lowest rate was observed in Guizhou (0.059 t ha$^{-1}$ yr$^{-1}$). This indicates that the development of rice production is uneven from province to province in southern China and suggests that more efforts should be made to breed new cultivars with higher yield potential and improve management practices in economically underdeveloped provinces such as Guizhou.

The relative yield residuals significantly decreased in 10 of the 12 provinces (Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Yunnan, and Zhejiang), in southern China. Data were collected from World Rice Statistics database for the years 1949–2013 (IRRI, 2018) and the database of National Bureau of Statistics of China (2018) for 2014 and 2015. The regression model was $y = a + bx$, where $y$ stands for the grain yield, $a$ the intercept, $b$ the rate of yield gain, and $x$ the year.

Wide adaptability has been one of the primary objectives in many rice breeding programs, including a national mega-project on the development of super hybrid rice established in 1998 in China (Chen et al., 2007; Wu, 2009). In recent years, significant progress has been made in the super hybrid rice breeding in China (Peng et al., 2008; Ma and Yuan, 2015). For crop management, several climate-smart management practices, such as the system of rice intensification (Thakur and Uphoff, 2017), have been adopted for rice production in southern China (Wu et al., 2015). Moreover, rice farmers in China often adjust their farm management practices...
(e.g., reseeding, fixing, and cleaning seedlings) in response to extreme weather events such as drought and flood (Huang et al., 2015), which can help to stabilize production.

To increase public services, Chinese meteorological departments have undertaken multilevel and multifield services based on different types of meteorological disasters and their damages to agriculture (Huailiang et al., 2011). The availability of disaster warning information can increase farmers’ awareness of threats posed by extreme weather events. In addition, governmental agencies, academic institutions, and universities have taken the initiative to provide technical guidance to farmers during and after disasters by sending technical experts.

Guizhou is an economically underdeveloped province, and rice research and production in this province have fallen behind that in the other provinces in southern China. Moreover, traditional rice cultivars still occupy 9 to 14% of the total rice-planting area in Guizhou (Jiao et al., 2015). These factors may have contributed to the insignificant change of rice yield stability in Guizhou. By contrast, Guangdong is an economically developed province, and research on rice breeding and management is also well advanced in this province. However, Guangdong is also the most typhoon-prone province in China, a problem compounded by the increase in the number of the typhoon events during the last half-century (Zhang et al., 2011). This could explain why rice yield stability has not significantly changed in this province.

Our study highlights the need for continuing efforts to develop new cultivars, improve crop management practices, and strengthen public services to maintain rice yield stability in southern China, especially in Guizhou, where rice research and production are relatively stagnant. In coastal provinces such as Guangzhou, where typhoons are a common occurrence, efforts should focus in part on breeding lodging-resistant cultivars and developing management practices which reduce lodging risk. We believe that a stable increase in rice production is achievable in southern China with ongoing scientific, technological and social innovations.

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References


Table 1. Number of cultivars released in 12 provinces in southern China, 1949–2015.†

<table>
<thead>
<tr>
<th>Province</th>
<th>Cultivar type</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inbred</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Anhui</td>
<td>124</td>
<td>260</td>
</tr>
<tr>
<td>Fujian</td>
<td>57</td>
<td>266</td>
</tr>
<tr>
<td>Guangdong</td>
<td>264</td>
<td>405</td>
</tr>
<tr>
<td>Guangxi</td>
<td>107</td>
<td>587</td>
</tr>
<tr>
<td>Guizhou</td>
<td>72</td>
<td>201</td>
</tr>
<tr>
<td>Hubei</td>
<td>73</td>
<td>220</td>
</tr>
<tr>
<td>Hunan</td>
<td>113</td>
<td>495</td>
</tr>
<tr>
<td>Jiangsu</td>
<td>244</td>
<td>110</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>132</td>
<td>553</td>
</tr>
<tr>
<td>Sichuan</td>
<td>43</td>
<td>364</td>
</tr>
<tr>
<td>Yunnan</td>
<td>222</td>
<td>149</td>
</tr>
<tr>
<td>Zhejiang</td>
<td>233</td>
<td>209</td>
</tr>
<tr>
<td>Total</td>
<td>1684</td>
<td>3819</td>
</tr>
</tbody>
</table>

† Data were collected from the China Rice Data Center (2018). The period corresponds with that for yield data collection.


