GRAIN YIELD STABILITY OF INBRED LATE RICE UNDER DOUBLE RICE CROPPING SYSTEM IN SOUTH CHINA

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Abstract. The objective of this study was to evaluate the grain yield of inbred late rice under the double rice cropping system in South China. A three years field experiment from 2015 to 2017 was conducted by using the inbred late rice variety grown under the double rice cropping system in South China. The grain yield and yield components, growth period, and some agronomic traits were recorded. Results indicated that the grain yield and yield components, growth period, and some agronomic traits were not changed in different planting years, except for the plant height. The mean grain yield was 6.36 t ha^{-1}, 6.30 t ha^{-1}, and 6.27 t ha^{-1} in 2015, 2016, and 2017, respectively. Different experiment locations recorded different yields due to the environmental difference which resulted in a change in the growth parameters. The stability of grain yield for the inbred late rice under the double rice cropping system in South China is highly related to the daily yield production ($r = 0.9712$, $p < 0.05$) grain number per panicle ($r = 0.3715$, $p < 0.05$), filled grain percentage ($r = 0.4016$, $p < 0.05$), and panicle length ($r = 0.3446$, $p < 0.05$). The finding of this study suggested that the grain number per panicle and filled grain percentage is critically important for the purpose of graining higher grain yield of inbred late rice under the double rice cropping system in South China.

Keywords: *grain yield, agronomic traits, yield components, inbred rice, yield stability*

Introduction

Rice is a staple crop in China, and increasing grain yield is crucial for rice production under different environmental conditions to sustain the growing population (Zhang, 2007). Increasing the grain yield per unit of land and the frequency of crop harvests are two planting strategies to increase grain production, according to Peng (2014). After reaching a high grain yield, maintaining a higher grain yield level or keeping grain yield stability at a high level is important to ensure food security.

The grain yield of rice has rapidly increased due to the development of hybrid rice (Yuan et al., 1994). Several studies reported that hybrid rice produced a higher cereal yield than inbred rice. (Peng et al., 1999; Zhang and Wang, 2006; Zhang et al., 2009; Huang et al., 2010). In general, hybrid seeds are more expensive than inbred cultivars; consequently, many producers favor the latter. China’s hybrid rice cultivation area has begun to decrease in recent years (Peng, 2016). Since 1995, the planting area of hybrid rice in China has decreased substantially (Huang and Zou, 2018). It means that the inbred rice cultivar plays an important role in recent rice production in the double rice cropping system in Southern China. Huang et al. (2020) indicated that the contribution of crop improvement to the yield improvement of double-cropped inbred rice in China may not be as substantial as previously believed. The production of inbred rice in the Guangdong

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region is increasing. Therefore, the yield enhancement or yield stability of inbred rice in the double rice cropping system of southern China requires additional consideration.

Different environmental conditions resulted in yield differences, especially, the climatic conditions that influenced the growth and productivity of rice significantly (Borrell et al., 1998; Jiang et al., 2015, 2016). The different environmental conditions resulted in the difference in temperature and radiation, which in turn influenced the formation of rice cereal yield (Katsura et al., 2008; Mo et al., 2015; Li et al., 2019; Liu et al., 2019a, b). Besides, previous studies indicated that the agronomic parameters like the panicle number, spikelet number per panicle, spikelet filling percentage, and grain weight are highly related to grain yield (Zhang et al., 2009; Huang et al., 2010, 2018). Shereen et al. (2005) attributed the decrease in grain yield of inbred rice under saline conditions to the decrease in panicle number and grain-filled rate, and Tao et al. (2022) suggested that the stabilization of panicle number and the grain-filled rate was beneficial to the yield of inbred rice. Thus, understanding the factors that are related to the grain yield stability of inbred rice under the double rice cropping system is essential.

The tillering capacity and panicle size of inbred rice were found to be disadvantaged compared to those of hybrid rice (Huang et al., 2012). The previous study suggested that the grain number per panicle and filled grain number per panicle are critical parameters for grain productivity in the early season in the double rice cropping system in Southern China (Zhao et al., 2020). The objective of this study was to provide a theoretical basis to better understand what parameters contributed to the grain yield of the late season in the double rice cropping system in South China and to provide evidence for management for improving or maintaining high yield in the late season in the double rice cropping system in Southern China.

Materials and methods

Experimental description

In the typical rice (*Oryza sativa* L.) production areas of Guangdong province, China, field experiments were conducted in 12 various locations from July to November between 2015 and 2017. The 12 locations cities represent different rice planting regions of Guangdong Province, China, and they were as follows: Chaozhou. Gaozhou, Guangzhou, Huilai, Huizhou, Longchuan, Luoding, Qingyuan, Xinhui, Yangjiang, Zhanjiang, and Zhaoqing. The climate data for the 12 locations during the rice growing season in 2015-2017 is shown in *Table 1*. The experimental fields were typical rice production fields that had been cultivated with rice for many years.

Table 1. *The climate data during the rice growth season of the 12 locations during 2015-2017*

Year	Site	Average temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)
2015	Chaozhou	26.1	23.1	31.1
	Gaozhou	27.4	24.1	32.2
	Guangzhou	25.8	22.7	30.7
	Huilai	26.9	24.3	30.6

	Huizhou	26.6	23.6	31.1
	Longchuan	25.8	22.2	31.0
	Luoding	26.4	23.0	31.4
	Qingyuan	27.3	24.2	31.7
	Xinhui	27.7	25.1	31.2
	Yangjiang	26.7	24.2	30.4
	Zhanjiang	27.5	24.7	31.2
	Zhaoqing	28.0	25.1	32.1
2016	Chaozhou	27.0	23.2	32.5
	Gaozhou	28.3	25.0	33.4
	Guangzhou	26.3	23.3	31.1
	Huilai	26.4	24.1	29.8
	Huizhou	26.6	23.8	31.0
	Longchuan	25.8	22.8	30.8
	Luoding	26.7	23.5	31.6
	Qingyuan	27.5	24.6	32.0
	Xinhui	27.8	25.3	31.4
	Yangjiang	27.1	24.6	30.8
	Zhanjiang	27.7	25.0	31.4
	Zhaoqing	27.6	24.7	32.0
2017	Chaozhou	26.2	23.4	29.6
	Gaozhou	27.9	24.7	33.0
	Guangzhou	26.3	23.0	31.6
	Huilai	26.8	24.2	30.6
	Huizhou	27.1	24.0	31.8
	Longchuan	26.4	22.6	32.2
	Luoding	26.3	23.2	31.7
	Qingyuan	27.7	24.5	32.4
	Xinhui	27.9	25.2	31.6
	Yangjiang	26.9	24.4	30.6
	Zhanjiang	27.0	24.4	30.9
	Zhaoqing	27.1	24.1	32.2

In each location, the widely recognized rice cultivar ‘Yuejingsimiao 2’ was used. ‘Yuejingsimiao 2’ is an inbred rice cultivar with a growth duration of 110-120 d, grain number per panicle of 110, setting rate of 85%, and 1000-grain weight of 22 g was developed by the Guangdong Academy of Agricultural Science and released in 2010. The seeds were provided by the Guangdong Academy of Agricultural Science. This cultivar has been widely grown by rice farmers in Guangdong province for its stable yields.

Pre-germinated seeds were sown at the nursing bed. The seedlings were transplanted at a hill spacing of 20 cm × 20 cm with three seedlings per hill. Seedling age at transplanting was around 15 d. A total of 750 kg ha^{-1} of the compound fertilizer (N: P: K = 15%:15%:15%) was applied in two splits i.e., 60% as basal dose and 40% applied at tillering. The water management was as follows: flooding at the tillering stage; then draining at the late tillering stage; and finally intermittent irrigation with alternating re-flooding and moisture from the heading stage to the maturity stage. All other crop management practices, including pest and vegetation control, were carried out by provincial guidelines.

Sampling and measurements

Grain yield and yield-related traits

At maturity, grain yield was measured from a sampling area of 13.34 m^2 within each plot, threshed manually, and then sun-dried (adjusted to moisture content ~ 14%). Panicle number per m^2 was determined using 1 m^2 and three replicates. Twelves plants were harvested in each plot to measure panicle length, grain number per panicle, filled grain number per panicle, and filled grain percentage. Five random samples of 1000 grains were taken from filled grains and weighed to record the 1000-grain weight. Plant height was recorded from 10 plants in each plot whereas the productive tiller percentage was calculated by dividing the panicle tillers by the total number of tillers.

Agronomy traits measurement

The sowing date, transplanting date, heading date, full heading date, and maturity date were recorded during the experimental period. Then the growth stages and the growth duration of different growth periods of rice grown in 12 locations between 2015 and 2017 were determined. The daily yield production (kg ha^{-1}) was calculated as grain yield (t ha^{-1}) divided by the growth duration (d). During 2015-2017, the maximum tiller number, percentage of the productive tiller, plant height, and panicle length of rice grown in 12 locations were also recorded.

Statistical analysis

Data were analyzed using ANOVA, whereas the means of years were compared based on the least significant difference test (LSD) at the 5% probability level. The correlation between the investigated parameters was investigated (Statistix 8, Analytical Software, Tallahassee, Florida, USA).

Results

The sowing dates for late-season rice in the double rice cropping system were from 5 to 25 July in 2015, 8 to 24 July in 2016, and 7 to 26 July in 2017. The maturity dates were from 25-Oct to 15-Nov for 2015, from 22-Oct to 14-Nov for 2016, and from 23-Oct to 16-Nov for 2017 (*Table 2*).

Table 2. *The growth stages of rice grown under 12 locations during 2015-2017*

Year	Site	Sowing (date-month)	Transplanting (date-month)	Heading (date-month)	Full heading (date-month)	Maturity (date-month)
2015	Chaozhou	22-Jul	11-Aug	3-Oct	5-Oct	14-Nov
	Gaozhou	5-Jul	26-Jul	19-Sep	23-Sep	25-Oct
	Guangzhou	22-Jul	11-Aug	4-Oct	8-Oct	10-Nov
	Huilai	21-Jul	13-Aug	2-Oct	6-Oct	15-Nov
	Huizhou	15-Jul	8-Aug	1-Oct	4-Oct	10-Nov
	Longchuan	6-Jul	4-Aug	26-Sep	30-Sep	7-Nov
	Luoding	25-Jul	12-Aug	7-Oct	12-Oct	15-Nov
	Qingyuan	10-Jul	30-Jul	19-Sep	23-Sep	27-Oct
	Xinhui	17-Jul	4-Aug	3-Oct	7-Oct	7-Nov
	Yangjiang	20-Jul	11-Aug	1-Oct	3-Oct	10-Nov
	Zhanjiang	17-Jul	5-Aug	26-Sep	30-Sep	31-Oct
	Zhaoqing	11-Jul	30-Jul	20-Sep	23-Sep	26-Oct
2016	Chaozhou	22-Jul	11-Aug	3-Oct	5-Oct	11-Nov
	Gaozhou	8-Jul	28-Jul	19-Sep	25-Sep	22-Oct
	Guangzhou	22-Jul	10-Aug	1-Oct	5-Oct	9-Nov
	Huilai	18-Jul	10-Aug	1-Oct	5-Oct	14-Nov
	Huizhou	21-Jul	12-Aug	5-Oct	8-Oct	10-Nov
	Longchuan	9-Jul	5-Aug	27-Sep	2-Oct	7-Nov
	Luoding	24-Jul	12-Aug	6-Oct	11-Oct	14-Nov
	Qingyuan	11-Jul	3-Aug	20-Sep	25-Sep	31-Oct
	Xinhui	19-Jul	5-Aug	4-Oct	8-Oct	8-Nov
	Yangjiang	20-Jul	10-Aug	29-Sep	2-Oct	10-Nov
	Zhanjiang	18-Jul	5-Aug	27-Sep	1-Oct	5-Nov
	Zhaoqing	11-Jul	31-Jul	26-Sep	29-Sep	2-Nov
2017	Chaozhou	21-Jul	10-Aug	1-Oct	5-Oct	8-Nov
	Gaozhou	11-Jul	29-Jul	19-Sep	24-Sep	23-Oct
	Guangzhou	26-Jul	15-Aug	6-Oct	9-Oct	13-Nov
	Huilai	24-Jul	13-Aug	3-Oct	7-Oct	16-Nov
	Huizhou	19-Jul	8-Aug	3-Oct	5-Oct	9-Nov
	Longchuan	7-Jul	30-Jul	25-Sep	28-Sep	2-Nov
	Luoding	22-Jul	11-Aug	7-Oct	11-Oct	17-Nov
	Qingyuan	10-Jul	3-Aug	20-Sep	25-Sep	30-Oct
	Xinhui	20-Jul	5-Aug	2-Oct	6-Oct	9-Nov
	Yangjiang	19-Jul	10-Aug	1-Oct	3-Oct	8-Nov
	Zhanjiang	21-Jul	8-Aug	1-Oct	5-Oct	9-Nov
	Zhaoqing	12-Jul	2-Aug	27-Sep	29-Sep	6-Nov

There were 18-29 days (average 21.08 days), 18-28 days (average 21.58 days), and 16-24 days (average 20.17 days) between sowing and transplanting for 2015, 2016, and

2017 year, respectively. The transplanting-heading durations were 53-64 days (average 57.00 days), 53-64 days (average 57.33 days), and 53-62 days (average 57.25 days) for 2015, 2016, and 2017, respectively. For the years 2015, 2016, and 2017, the growth period for heading - maturity was 31-40 days (average 35.08 days), 27-40 days (average 34.75 days), and 29-40 days (average 35.25 days), respectively (*Table 3*).

Table 3. *The growth duration of different growth period of rice grown under 12 locations during 2015-2017*

Year	Site	Sowing - transplanting (d)	Transplanting - heading (d)	Heading - maturity (d)
2015	Chaozhou	20	55	40
	Gaozhou	21	59	32
	Guangzhou	20	58	33
	Huilai	23	54	40
	Huizhou	24	57	37
	Longchuan	29	57	38
	Luoding	18	61	34
	Qingyuan	20	55	34
	Xinhui	18	64	31
	Yangjiang	22	53	38
	Zhanjiang	19	56	31
	Zhaoqing	19	55	33
	Mean	**21.08 a**	**57.00 a**	**35.08 a**
2016	Chaozhou	20	55	37
	Gaozhou	20	59	27
	Guangzhou	19	56	35
	Huilai	23	56	40
	Huizhou	22	57	33
	Longchuan	28	58	36
	Luoding	19	60	34
	Qingyuan	23	53	36
	Xinhui	26	64	31
	Yangjiang	21	53	39
	Zhanjiang	18	57	35
	Zhaoqing	20	60	34
	Mean	**21.58 a**	**57.33 a**	**34.75 a**
2017	Chaozhou	20	56	34
	Gaozhou	18	57	29
	Guangzhou	20	55	35
	Huilai	20	55	40
	Huizhou	20	58	35
	Longchuan	23	60	35

	Luoding	20	61	37
	Qingyuan	24	53	35
	Xinhui	16	62	34
	Yangjiang	22	54	36
	Zhanjiang	18	58	35
	Zhaoqing	21	58	38
	Mean	**20.17 a**	**57.25 a**	**35.25 a**

Lowercase letter represents significant difference at $P < 0.05$ level between years

The grain yield ranged from 3.43-8.07 t ha^{-1}, 5.10-7.68 t ha^{-1}, and 4.28-7.42 t ha^{-1} for 2015, 2016, and 2017 year. The mean grain yield was 6.36 t ha^{-1}, 6.30 t ha^{-1}, and 6.27 t ha^{-1} in 2015, 2016, and 2017 year, respectively. There were significant differences in grain yield at different locations. The higher average yields were reached in Chaozhou, Luoding, and Guangzhou in 2015, 2016, and 2017, respectively. The mean growth duration for 2015, 2016, and 2017 years was 113.17 days, 112.83 days, and 112.67 days, respectively. The changes in daily yield production for the years 2015, 2016, and 2017 were calculated to be 56.07 kg ha^{-1}, 56.00 kg ha^{-1}, and 55.72 kg ha^{-1}, respectively. Across different locations, the daily yield production ranged from 38.30 to 70.15 kg ha^{-1}, 42.13 to 67.92 kg ha^{-1}, and 38.21 to 62.35 kg ha^{-1} for 2015, 2016, and 2017 years, respectively (*Table 4*).

Table 4. *Grain yield, whole growth duration, and daily yield production of rice grown under 12 locations during 2015-2017*

Year	**Site**	**Grain yield (t ha^{-1})**	**Growth duration (d)**	**Daily yield production (kg ha^{-1})**
2015	Chaozhou	8.07a	115.0	70.15
	Gaozhou	5.61f	112.0	50.11
	Guangzhou	6.65de	111.0	59.89
	Huilai	7.15bc	117.0	61.13
	Huizhou	7.00cd	118.0	59.32
	Longchuan	7.26bc	124.0	58.57
	Luoding	7.55b	113.0	66.84
	Qingyuan	6.37e	109.0	58.44
	Xinhui	6.30e	113.0	55.75
	Yangjiang	4.33g	113.0	38.30
	Zhanjiang	3.43h	106.0	32.31
	Zhaoqing	6.64de	107.0	62.06
	Mean	**6.36 A**	**113.17 a**	**56.07 a**
2016	Chaozhou	5.47f	112.0	48.79
	Gaozhou	6.00de	106.0	56.60
	Guangzhou	7.07b	110.0	64.30
	Huilai	5.81e	119.0	48.84
	Huizhou	6.31cd	112.0	56.34
	Longchuan	5.10g	121.0	42.13

	Luoding	7.68a	113.0	67.92
	Qingyuan	6.98b	112.0	62.28
	Xinhui	6.08cde	112.0	54.24
	Yangjiang	6.02cde	113.0	53.25
	Zhanjiang	6.79b	110.0	61.73
	Zhaoqing	6.34c	114.0	55.61
	Mean	**6.30 A**	**112.83 a**	**56.00 a**
2017	Chaozhou	6.38d	110.0	58.02
	Gaozhou	6.47cd	104.0	62.21
	Guangzhou	7.42a	110.0	67.41
	Huilai	6.83b	115.0	59.39
	Huizhou	5.57g	113.0	49.31
	Longchuan	6.41d	118.0	54.34
	Luoding	5.80fg	118.0	49.13
	Qingyuan	6.08e	112.0	54.24
	Xinhui	5.99ef	112.0	53.46
	Yangjiang	4.28h	112.0	38.21
	Zhanjiang	6.72bc	111.0	60.50
	Zhaoqing	7.30a	117.0	62.35
	Mean	**6.27 A**	**112.67 a**	**55.72 a**

Capital letters represents significant difference of grain yield at the $P < 0.05$ level between years. Lowercase letter represents significant difference at $P < 0.05$ level between locations

The average panicle number per m^2 was 302.66 in 2015 (250.5-405.0 at different locations), 284.69 in 2016 (262.5-306.0 at different locations), and 298.62 in 2017 (240.0-457.5 at different locations). The mean grain number per m^2 in 2015, 2016, and 2017 years were 132.82, 149.87, and 141.14. The average filled grain percentage was 79.50% in 2015 (69.4-94.0% at different locations), 78.83% in 2016 (63.5-93% at different locations), and 80.75% in 2017 (72.2-87.6% at different locations). The mean grain weight was 21.05-21.18 mg (*Table 5*).

Table 5. *Yield components under 12 locations during 2015-2017*

Year	**Site**	**Panicle number per m^2**	**Grain number per panicle**	**Filled grain percentage (%)**	**Grain weight (mg)**
2015	Chaozhou	297.2	126.1	94.0	21.9
	Gaozhou	298.5	121.6	81.8	21.1
	Guangzhou	280.5	147.3	75.6	21.0
	Huilai	303.0	140.5	78.5	21.3
	Huizhou	405.0	126.1	74.0	20.4
	Longchuan	359.9	148.4	68.3	20.2
	Luoding	267.0	189.7	90.9	23.1
	Qingyuan	282.0	145.3	83.4	20.6
	Xinhui	315.4	110.3	69.4	21.3
	Yangjiang	250.5	115.5	70.8	21.6

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	Zhanjiang	238.5	102.4	81.8	20.2
	Zhaoqing	334.5	120.7	85.5	20.0
	Mean	**302.66 a**	**132.82 a**	**79.50 a**	**21.05 a**
2016	Chaozhou	280.1	150.5	63.5	21.3
	Gaozhou	273.0	132.4	91.2	22.4
	Guangzhou	262.5	166.7	75.7	20.9
	Huilai	279.0	129.8	75.4	21.8
	Huizhou	295.5	151.0	75.7	21.8
	Longchuan	289.8	173.5	60.7	21.4
	Luoding	300.0	195.6	93.0	24.2
	Qingyuan	313.5	134.4	85.7	20.8
	Xinhui	280.0	144.7	81.5	21.7
	Yangjiang	252.0	160.6	72.1	22.4
	Zhanjiang	285.0	136.8	89.3	21.8
	Zhaoqing	306.0	122.5	80.9	23.6
	Mean	**284.69 a**	**149.87 a**	**78.73 a**	**22.01 a**
2017	Chaozhou	260.0	138.0	87.6	20.3
	Gaozhou	297.0	137.5	78.9	21.9
	Guangzhou	273.0	169.4	75.5	18.4
	Huilai	277.5	136.8	81.1	22.7
	Huizhou	457.5	114.8	72.2	21.3
	Longchuan	287.1	135.3	78.9	22.0
	Luoding	285.0	191.4	93.5	21.2
	Qingyuan	312.0	146.8	77.8	20.7
	Xinhui	303.4	126.0	77.5	19.9
	Yangjiang	240.0	130.3	73.3	21.3
	Zhanjiang	301.5	131.1	86.6	21.8
	Zhaoqing	289.5	136.3	86.1	22.6
	Mean	**298.62 a**	**141.14 a**	**80.75 a**	**21.18 a**

Lowercase letter represents significant difference at $P < 0.05$ level between years

The average maximum tiller number per m^2 and percentage of productive tiller were 431-471 tillers per m^{-2} and 63.24-66.46%, respectively. In 2017, the plant height was significantly higher than in 2015 and 2016. The average panicle length was 22.33-23.09 cm (*Table 6*).

Table 6. *Maximum tiller number, percentage of productive tiller, plant height, and panicle length of rice grown under 12 locations during 2015-2017*

Year	**Site**	**Maximum tiller number per m^2**	**Percentage of productive tiller (%)**	**Plant height (cm)**	**Panicle length (cm)**
2015	Chaozhou	411	72.2	113.5	21.4
	Gaozhou	409	73.0	101.7	22.2
	Guangzhou	441	63.6	116.0	24.0

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	Huilai	525	57.7	92.8	22.5
	Huizhou	556	72.8	106.0	22.5
	Longchuan	425	84.7	101.0	22.7
	Luoding	358	74.5	113.5	25.9
	Qingyuan	397	70.9	105.4	22.7
	Xinhui	628	50.2	103.0	22.2
	Yangjiang	474	52.8	94.6	19.4
	Zhanjiang	465	51.3	104.8	21.1
	Zhaoqing	453	73.8	102.6	21.3
	Mean	**462 a**	**66.46 a**	**104.58 b**	**22.33 a**
2016	Chaozhou	331	84.5	112.5	23.1
	Gaozhou	456	59.7	99.9	23.3
	Guangzhou	343	76.4	106.5	24.1
	Huilai	511	54.5	104.6	21.8
	Huizhou	346	85.3	110.0	23.0
	Longchuan	351	82.6	99.0	25.0
	Luoding	457	65.6	105.8	24.6
	Qingyuan	453	69.2	103.9	22.5
	Xinhui	482	58.1	101.5	21.7
	Yangjiang	505	49.9	98.1	24.3
	Zhanjiang	510	55.9	98.0	21.2
	Zhaoqing	427	71.6	93.4	22.5
	Mean	**431 a**	**67.76 a**	**102.77 b**	**23.09 a**
2017	Chaozhou	427	60.8	112.9	22.1
	Gaozhou	444	67.0	109.6	24.3
	Guangzhou	438	62.3	109.9	23.7
	Huilai	475	58.4	109.6	22.4
	Huizhou	604	75.7	112.0	23.1
	Longchuan	438	65.6	106.0	22.7
	Luoding	475	59.9	109.7	24.7
	Qingyuan	493	63.2	107.6	21.1
	Xinhui	495	61.3	121.5	22.8
	Yangjiang	381	63.0	102.6	21.5
	Zhanjiang	534	56.5	111.2	22.9
	Zhaoqing	444	65.2	114.6	22.8
	Mean	**471 a**	**63.24 a**	**110.60 a**	**22.84 a**

Lowercase letter represents significant difference at P < 0.05 level between year

Table 7 demonstrates a strong correlation between the grain yield and the daily yield production (r = 0.9712, $p < 0.05$), grain number per panicle (r = 0.3715, $p < 0.05$), filled grain percentage (r = 0.4016, $p < 0.05$), and panicle length (r = 0.3446, $p < 0.05$).

Table 7. *The correlation relationship between the grain yield and other investigated parameters*

Index	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A2	**0.9712 ****												
A3	-0.0875 ns	-0.2399 ns											
A4	0.0428 ns	-0.1156 ns	**0.5762 ****										
A5	0.1587 ns	0.1711 ns	-0.2742 ns	0.0404 ns									
A6	0.1727 ns	-0.0637 ns	**0.6476 ****	**0.6821 ****	-0.0349 ns								
A7	0.2519 ns	0.1882 ns	0.1818 ns	0.3273 ns	-0.0045 ns	0.2798 ns							
A8	**0.3715 ***	**0.3371 ***	0.0977 ns	0.1640 ns	0.1899 ns	0.2147 ns	-0.2215 ns						
A9	**0.4016 ***	**0.4690 ****	**-0.4376 ****	-0.2333 ns	-0.0508 ns	-0.2987 ns	-0.1578 ns	0.1379 ns					
A10	0.1599 ns	0.1321 ns	-0.1111 ns	0.1253 ns	-0.0011 ns	0.1239 ns	-0.1313 ns	0.2049 ns	0.2996 ns				
A11	-0.0014 ns	-0.0200 ns	-0.1270 ns	0.0413 ns	0.1668 ns	0.0539 ns	**0.4746 ****	**-0.4251 ****	0.0221 ns	-0.0480 ns			
A12	0.2285 ns	0.1845 ns	0.2978 ns	0.2889 ns	-0.1096 ns	0.2245 ns	0.3979 ns	0.2511 ns	-0.2351 ns	-0.0564 ns	**-0.6053 ****		
A13	0.2412 ns	0.2708 ns	**-0.4098 ***	-0.1320 ns	0.2628 ns	-0.1251 ns	0.0907 ns	0.1421 ns	0.1744 ns	-0.1774 ns	-0.1096 ns	0.1755 ns	
A14	**0.3446 ***	**0.3375 ***	-0.1128 ns	0.2541 ns	**0.4072 ***	0.0997 ns	0.0157 ns	**0.7530 ****	0.0293 ns	0.2397 ns	-0.2766 ns	0.3191 ns	0.2954 ns

A1: grain yield, A2: Daily yield production A3: Sowing-transplanting period, A4: Transplanting-heading period, A5: Heading-maturity period, A6: Growth duration, A7: Panicle number per m^2, A8: Grain number per panicle, A9: Filled grain percentage, A10: Grain weight, A11: Maximum tiller number per m2, A12: Percentage of productive tiller, A13: Plant height, A14: Panicle length. * and ** represent significance at 0.05 and 0.01 level, ns means not significant

Discussion

This study suggested that the grain yield of inbred late rice under the double rice cropping system was highly related to the grain number per panicle and filled grain percentage. Various climatic conditions, geographic locations, and rice agronomic characteristics led to this result.

Firstly, climatic conditions influenced rice growth and yield due to temperature and radiation differences (Borrell et al., 1998; Jiang et al., 2015, 2016; Katsura et al., 2008; Mo et al., 2015; Li et al., 2019; Liu et al., 2019a, b). In this study, the growth stages and the growth duration of various growth period of rice grown in 12 locations was different, resulting in the changes in the difference in utilization of temperature and light resources as well as in facing some potential adversity stress. In a previous study, Huang et al. (2020) found that the maximum yield difference between two inbred rice cultivars was only about 5%. There may be some variation in grain yield between the various inbred rice cultivars, but the variation is likely to be minor. It was suggested that the planting location significantly affected the grain yield.

Besides, the results in this study indicated that the grain yield and yield components, growth period, and some agronomic traits were not changed in different planting years, except for the plant height. Grain yield is affected by the growth duration (Zhang et al., 2009). In this study, the grain yield in different locations, the grain yield was different for different years. Due to the difference in the mean growth duration, the daily yield production was 38.30-70.15 kg ha^{-1}, 42.13-67.92 kg ha^{-1}, and 38.21-62.35 kg ha^{-1} in different locations for 2015, 2016, and 2017 years, respectively. And in this study, it was found that the grain yield was significantly related to the daily yield production. Therefore, the final grain yield may be affected by the daily yield production.

Moreover, for the yield components, the panicle number per m^2 was 250.5-405.0 in 2015, 262.5-306.0 in 2016, and 240.0-457.5 in 2017. The grain number per panicle was 102.4-189.7 in 2015, 122.5-195.6 in 2016, and 114.8-191.4 in 2017. The filled grain percentage was 69.4-94.0% in 2015, 63.5-93% in 2016, 72.2-87.6% in 2017. The grain weight variation was very low. Jiang et al. (2015, 2016) reported that, except for genetic determinants, differences in grain yield between hybrid rice and inbred cultivars are dependent on external environmental conditions. A study suggested that the grain number per panicle and filled grain number per panicle are critical parameters for grain productivity in the early season in the double rice cropping system in Southern China (Zhao et al., 2020). Therefore, the variations in panicle number per m^2, grain number per panicle, and filled grain percentage as well as few agronomic traits could be the key parameters for the grain yield stability of inbred late rice under the double rice cropping system.

In addition, the previous study has reported the correlation between grain yield and spikelet number per panicle (Zhang et al., 2009), panicle numbers (Huang et al., 2010), and grain filling percentage (Huang et al., 2018). Different experiment locations recorded different yields due to the environmental difference which result in a change in the growth parameters. In this study, further analysis of the correlation relationship between the grain yield and other investigated parameters indicated that the daily yield production grain number per panicle, filled grain percentage, and panicle length were important for the grain yield improvement of the inbred late rice under the double rice cropping system in South China.

Conclusion

Different experiment locations recorded different yields due to the environmental difference which resulted in a change in the agronomic parameters and grain yield and yield components. The stability of grain yield for the inbred late rice under the double rice cropping system in South China is highly related to the daily yield production, grain number per panicle, filled grain percentage, and panicle length. Results suggested that the grain number per panicle and filled grain percentage are critically important in South China.

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