RESEARCH

Relationships between grain yield and agronomic traits of rice in southern China

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ABSTRACT

Field experiments were conducted to evaluate the grain yield and agronomic traits of inbred and hybrid rice (*Oryza sativa* L.) 'Yuxiangyouzhan' and 'Shenliangyou 58 xiangyouzhan' at 11 different planting sites during 2013-2017 in Southern China. The grain yield, growth period, panicle number m^{-2}, productive tiller percentage, plant height, panicle length, grain number per panicle, filled grain number per panicle, filled grain percentage, and grain weight were evaluated. Results indicated that 'Shenliangyou 58 xiangyouzhan' produced higher grain yields than 'Yuxiangyouzhan' which was attributed to high grain weight and panicle length. Grain yield showed an increasing trend during 2013-2017 and the yield gaps among different years were attributed to differences in plant height, filled grain percentage and grain weight. The differences in grain yield among sites were mostly due to the combination effect of the agronomic traits which was greatly affected by the different climate conditions. The grain yield was significantly and positively correlated with the plant height, grain number m^{-2}, filled grain number per panicle, filled grain percentage and grain weight. Moreover, principal components analysis (PCA) suggested that grain number per panicle and filled grain number per panicle are critical parameters attributed to grain productivity. Therefore, flowering and post-flowering stage is the most critical in this regard to improve the grain number and filled grain number per panicle to get better yields in the agro-climatic conditions of southern China.

Key words: Agronomic traits, China, grain yield, rice.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the world population. Strategies are needed to increase the grain production to meet the food requirement of ever-increasing population (Zhang, 2007). It is impossible to increase rice planting area to gain higher rice production, so to increase grain yield per unit area and crop harvest frequency is the only option to get maximum returns (Ray and Foley, 2013; Peng, 2014). The development of hybrid rice resulted in rapid increment in rice yield (Yuan et al., 1994). Hybrid rice produced higher grain yield than inbred rice (Zhang and Wang, 2006). Peng et al. (1999) indicated that hybrid rice produced 9% higher yields than the best inbred cultivars in tropical irrigated lowlands. Other field studies suggested that grain yield of super hybrid rice yield over 10% higher than that of inbred rice (Zhang et al., 2009; Huang et al., 2010). Southern China is a typical region with adequate light and temperature resources quite suitable for double rice production systems.

Previous field studies showed yield differences among the same rice types/cultivars under different environmental conditions. For example, Taoyuan, Yunnan Province, China, had higher grain yield than other rice planting sites (Katsura et al., 2008), hence prevailing climatic conditions have huge impact in the growth and overall productivity of rice (Borrell et al., 1998; Jiang et al., 2015; 2016). The different environmental conditions results in the difference in temperature and radiation which ultimately affected grain yield formation in rice (Katsura et al., 2008; Mo et al., 2015; Li et al., 2019; Liu et al., 2019a; 2019b).

Moreover, a number of studies demonstrated that agronomic traits such as panicle number, spikelet number per panicle, spikelet filling percentage, and grain weight are highly related to grain yield, for example, Zhang et al. (2009) presented evidence that high grain yield of hybrid rice was associated with the spikelet number per panicle. Huang et al. (2010) suggested that grain yield in hybrid rice was highly attributed to panicle numbers. Ao et al. (2008) and Zhang et al. (2009) suggested that long growth duration was partially responsible for high biomass production in hybrid rice which attributed high grain yield. Besides, yield stability was positively correlated with grain filling percentage (Huang et al., 2018). So, it is imperative to study how regionally variable environmental conditions affect yield of hybrid and inbred rice cultivars as well as the physiological basis of hybrid rice cultivars responsible for high grain productivity. The present study was therefore conducted at 11 different sites in southern China for a time period of 5 yr to assess yield variability among inbred and hybrid rice cultivars as well as the relationships between agronomic traits and grain yield.

MATERIALS AND METHODS

Experimental description

Field experiments were conducted in 11 different locations from February to July from 2013 to 2017 in the typical rice (*Oryza sativa* L.) production areas of Guangdong province, China. The 11 locations represent different rice planting regions of Guangdong Province, China, and they were as follows: northern regions (Heyuan, Qingyuan, Yunfu), north eastern regions (Heyuan), north western regions (Qingyuan, Yunfu), eastern regions (Chaozhou), central regions (Guangzhou, Huizhou, Jiangmen, Zhaoqing), and western regions (Zhanjiang, Maoming, Yangjiang). The average temperature, annual precipitation and annual sunshine hours of the experimental regions are shown in Table 1. The experimental fields were typical rice production field and had remained under rice cultivation for many years.

Two popular rice cultivars, i.e., Yuxiangyouzhan and Shenliangyou 58 xiangyouzhan, were used in each site. Yuxiangyouzhan is an inbred rice cultivar (growth duration 127 d, with 135 grains per panicle, 87% setting rate, and 22.7 g 1000-grain weight) developed by the Guangdong Academy of Agricultural Science and released in 2005. The 'Shenliangyou 58 xiangyouzhan' is a hybrid rice with a growth duration of 129 d, 145 grains per panicle, 77% setting

Table 1. Average temperature, annual precipitation and annual sunshine hours of the experimental regions.

Year	Northern regions	North eastern regions	North western regions	Eastern regions	Central regions	Western regions
Average temperature, °C						
2013	20.0	21.2	22.7	22.6	21.5	23.0
2014	20.4	21.7	22.8	22.8	21.7	23.3
2015	20.8	22.0	23.4	23.5	22.3	24.3
2016	20.7	21.7	22.5	23.3	22.0	23.6
2017	20.8	22.0	22.6	23.5	22.1	23.7
Annual precipitation, mm						
2013	1654.0	1930.2	1736.2	1887.2	2095.4	2084.2
2014	1517.0	1164.9	1788.2	1416.5	2234.0	1468.9
2015	2128.7	1696.3	1848.1	1446.6	2471.9	1328.9
2016	2428.9	2410.3	2132.5	2174.7	2939.7	1820.0
2017	1397.2	1396.3	1275.8	1419.0	2067.4	1760.7
Annual sunshine hours, h						
2013	1731.5	1827.8	1624.2	1865.8	1582.9	1811.2
2014	1886.2	1997.5	1744.5	1957.8	1613.6	1991.5
2015	1540.8	1740.4	1583.0	2010.7	1594.3	2008.1
2016	1629.2	1553.6	1466.2	1701.0	1451.8	1963.9
2017	1738.9	1831.4	1605.4	1994.6	1671.5	1891.9

rate, and 22.7 g 1000-grain weight, was developed by the Guangdong Academy of Agricultural Science and Tsinghua Shenzhen Longgang Research Institute, National Center for Engineering and Technology of Hybrid Rice and released in 2008. These cultivars have been widely grown by rice farmers in Guangdong province for their high yield potential.

Pre-germinated seeds were sown at 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 25-35 d. Total 750 kg hm^{-2} 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, midseason drainage, re-flooding and moist intermittent irrigation during the crop growth period. All other crop management practices, pest and weed management were performed following guidelines given for the province.

Grain yield and yield related traits

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

Statistical analysis

Data were analyzed using ANOVA, whereas means of cultivars, sites and 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). For multivariate analysis, data were imported into the MetaboAnalyst software (http://www.metaboanalyst.ca; Xia et al., 2009).

RESULTS AND DISCUSSION

'Shenliangyou 58 xiangyouzhan' produced significantly higher grain yield than 'Yuxiangyouzhan'. The highest grain yield was obtained for 2017 (6.83 t ha^{-1}) whilst significant lowest grain yield was recorded for 2013 (6.29 t ha^{-1}). Different planting sites showed difference in grain yield. The highest grain yield was observed for Yunfu (7.22 t ha^{-1}) whilst the lowest grain yield was detected for Yangjiang (5.40 t ha^{-1}). The highest grain was detected at Yunfu (7.98 t ha^{-1}) in 2017, whilst the lowest grain was detected at Yangjiang (3.39 t ha^{-1}) in 2014. Over all, 'Shenliangyou 58 xiangyouzhan' produced higher and more stable grain yield than 'Yuxiangyouzhan'. Grain yield showed an increasing trend during 2013-2017 and varied for different growing sites (Table 2). Jiang et al. (2016) stated that hybrid rice yielded approximately 8% more grain than inbred cultivars, besides, the reports of Zhang et al. (2009) and Huang et al. (2010) stated that grain yield of super hybrid rice was higher than that of inbred rice by more than 10%. Jiang et al. (2015; 2016) reported that the differences in grain yield between hybrid rice and inbred cultivars also depend on the external environmental conditions except genetic factors. Moreover, yield variations in yield components are largely responsible for yield variability for the inbred and hybrid rice cultivars, however external environmental conditions and cultivation practices could also be responsible for yield variability for the given rice types. Furthermore, difference between the percentage increment in our study and previous studies is mainly due to the long duration of rice cultivation owing to improvements in cultivation practices. Grain yield showed increasing trends during 2013-2017 across two cultivars and 11 planting sites, however, the strong annual precipitation and short annual sunshine hours in 2016 may relate to the slight decrease in grain yield in 2016 (Tables 1 and 2).

'Shenliangyou 58 xiangyouzhan' had higher growth period, plant height, panicle length, grain number per panicle, filled grain number per panicle, filled grain percentage, and grain weight but lower panicle number m^{-2} and productive tiller percentage than 'Yuxiangyouzhan'. Significant difference was observed in panicle length and grain weight between the two cultivars (Figure 1). Significant difference was observed in plant height, filled grain percentage and grain weight among the experimental years. The highest plant height, filled grain percentage and grain weight were observed in 2017, 2015 and 2015, respectively. The growth period, panicle number m^{-2}, productive tiller percentage, panicle length, grain

Table 2. Grain yield of inbred and hybrid rice cultivars in 5 years in 11 planting sites.

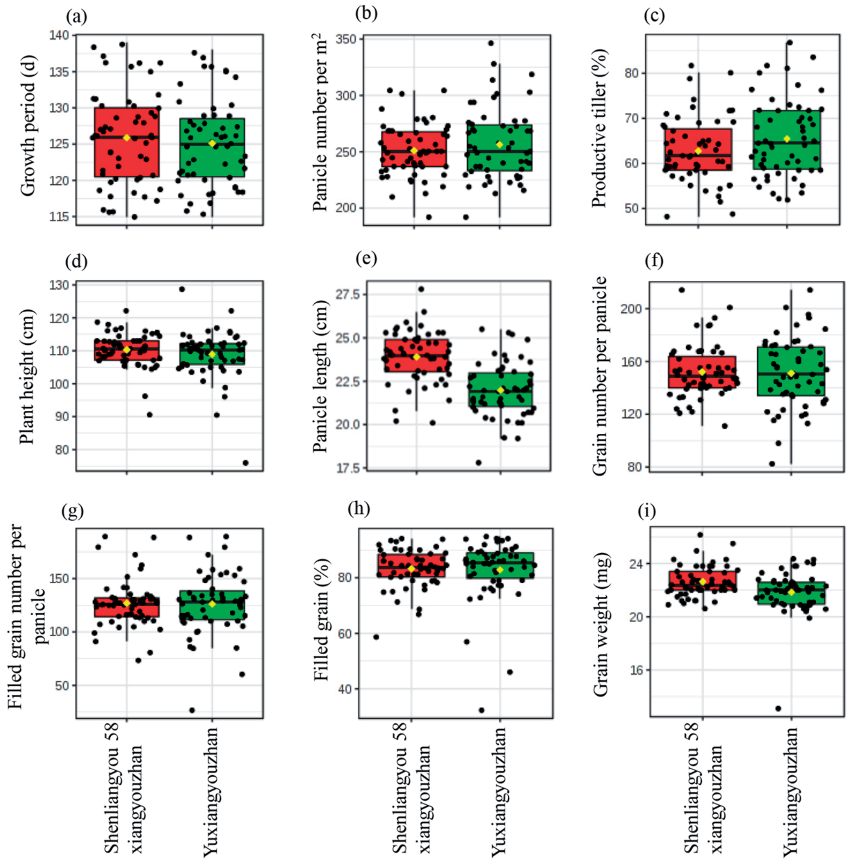
Treatment	Grain yield t ha^{-1}
Cultivars	
Yuxiangyouzhan	6.40b
Shenliangyou 58 xiangyouzhan	6.66a
Years	
2013	6.29e
2014	6.35d
2015	6.62b
2016	6.56c
2017	6.83a
Sites	
Chaozhou-Shantou	6.22f
Guangzhou	6.68d
Heyuan	5.93g
Huizhou	6.69d
Jiangmen	6.73cd
Maoming	6.66d
Qingyuan	7.02b
Yangjiang	5.40h
Yunfu	7.22a
Zhanjiang	6.78c
Zhaoqing	6.49e
ANOVA	
Cultivar (C)	**
Year (Y)	**
Site (S)	**
C×Y	**
C×S	**
Y×S	**
C×S×Y	**

Different lowercase letters represent significant difference at 5% level. **Significance at 1% level.

number per panicle, filled grain number per panicle for the experimental years were about 124-126 d, 249.05-259.13, 61.68%-66.55%, 22.57-23.46 cm, 138.66-158.94, and 122.27-132.78, respectively, across two cultivars and all growing sites (Figure 2). The panicle number m^{-2} and grain weight were 232.08-271.21 and 21.24-23.77 mg, respectively; the highest panicle number m^{-2} and grain weight was detected at Maoming. The productive tiller percentage, grain number per panicle, filled grain number per panicle, and filled grain percentage was 58.77%-71.65%, 138.06-193.22, 83.11-177.84, and 65.71%-92.13%, respectively. The highest productive tiller percentage, grain number per panicle, filled grain number per panicle, and filled grain percentage at Yunfu. The longest growth period was investigated for Chaozhou-Shantou (135.8 d), whilst the shortest growth period was detected for Maoming (117.2 d). The plant height and panicle length were 98.64-113.21 and 21.28-24.48 cm, respectively (Figure 3). Similarly, a number of studies have revealed the correlation between grain yield and spikelet number per panicle (Zhang et al., 2009), panicles numbers (Huang et al., 2010), growth duration (Ao et al., 2008; Zhang et al., 2009), and grain filling percentage (Huang et al., 2018). It is possible that growth duration is related to the grain yield as it affects the other agronomic traits as well. Moreover, Table 3 showed that significant and positive correlations between grain yield and plant height ($r = 0.3868$**), grain number m^{-2} ($r = 0.3349$**), filled grain number per panicle ($r = 0.5205$**), filled grain percentage ($r = 0.4958$**) and grain weight ($r = 0.1876$*) was detected. In addition, productive tiller percentage showed significant but negative correlation with grain weight. Further, significant and negative correlation between panicle number m^{-2} and growth period, panicle length, grain number per panicle, filled grain number per panicle was also detected.

The biomass accumulation is important for grain yield formation. The improvement in rice yield potential might come from increased the biomass production (Peng et al., 1999). Laza et al. (2003) observed a weak relationship between grain

Figure 1. Agronomy traits of inbred and hybrid rice cultivars plants. The data point means data in different years and locations for each variety.



yield and biomass production. Jiang et al. (2015) suggested that higher grain yield in hybrid than in inbred cultivars in Changsha was attributed to higher grain weight and higher biomass production. In this study, the biomass of rice plant was not investigated and further study to evaluate the relationship between biomass and yield, yield related traits and other agronomy traits under long term study is needed.

The principal components analysis (PCA) of the investigated parameters revealed that F1, F2, F3, F4 and F5 accounted for 82.2%, 9.0%, 3.6%, 3.2% and 1.4%, respectively (Figure 4). The grain number and filled grain numbers per panicle, and filled grain percentage were detected with high loading value for F1 whereas filled grain number per panicle and filled grain percentage were detected with high loading value for F2 (Table 4). These results suggested that grain yield was highly related to the grain number per panicle, filled grain number per panicle, and filled grain percentage.

Generally, suitable climatic conditions during the specific growth stage are critical for rice plant growth and grain yield. Therefore, further study to analyze the climate character during specific growth stages related to grain yield in long term experiments is needed.

Figure 2. Agronomy traits of rice plants during 2013-2017. The data point means data of the two varieties in 11 locations for each year.

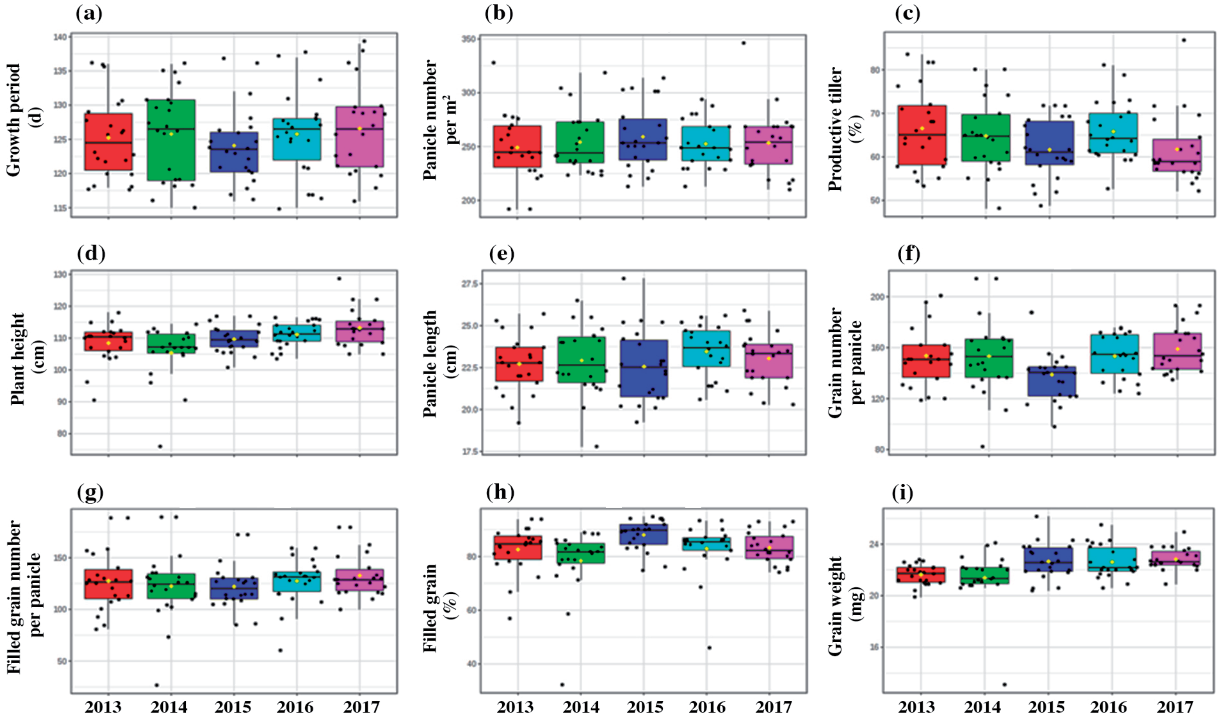


Figure 3. Agronomy traits of rice plants among different plant sites. The data point means data of the two varieties during 2013-2017.

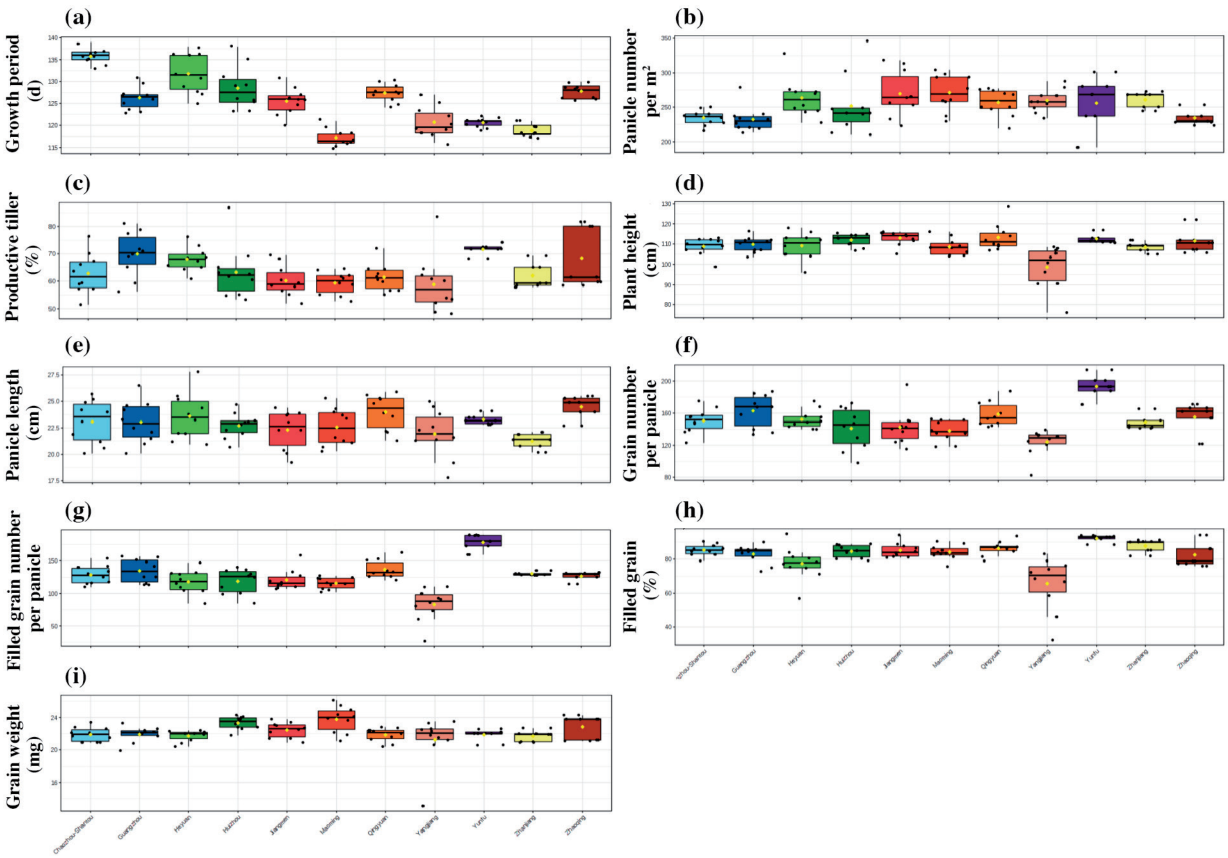


Table 3. Correlation analyses of the investigated parameters.

Parameters	GY	GP	PN	PT	PH	PL	GN	FGN	FGP
GP	-0.0897								
PN	0.0251	-0.1998							
PT	0.0203	0.1119	0.0227						
PH	0.3868**	0.2609**	-0.0131	-0.0057					
PL	0.1647	0.2839**	-0.2504	0.0525	0.3681**				
GN	0.3349**	0.0489	-0.2711**	0.4137**	0.4064**	0.4209**			
FGN	0.5205**	-0.0217	-0.2459**	0.3319**	0.4751**	0.3172**	0.8945**		
FGP	0.4958**	-0.0594	-0.0734	0.0296	0.4495**	0.0595	0.2841**	0.6676**	
GW	0.1876*	-0.0176	-0.0565	-0.2179*	0.4607**	0.3212**	0.0053	0.1454	0.4273**

GY: Grain yield; GP: growth period; PN: panicle number m^{-2}; PT: productive tiller percentage; PH: plant height; PL: panicle length; GN: grain number per panicle; FGN: filled grain number per panicle; FGP: filled grain percentage; GW: grain weight.
*, **Significant at the 5% and 1% probability levels, respectively.

Figure 4. Principal component analyses (PCA) of evaluated parameters.

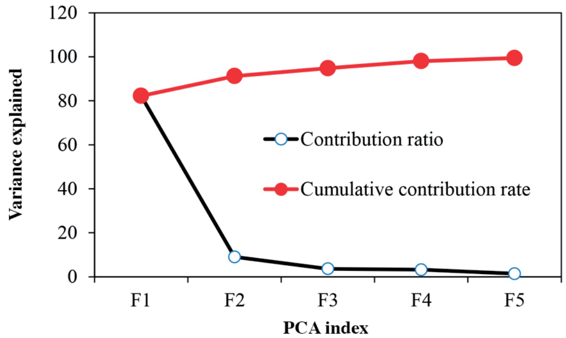


Table 4. Eigenvector of main factors analysis.

Factor	F1	F2	F3	F4	F5
Grain yield	0.0104	0.0249	0.0052	0.0005	0.0180
Growth period	0.0026	-0.0812	0.0347	-0.8030	-0.5755
Panicle number m^{-2}	-0.0139	0.0110	-0.0378	0.0163	0.1455
Productive tiller percentage	0.0901	-0.2551	-0.9102	-0.1918	0.2364
Plant height	0.0881	0.1434	0.2794	-0.5415	0.7463
Panicle length	0.0193	-0.0275	0.0635	-0.0789	0.0055
Grain number per panicle	0.6495	-0.5630	0.2209	0.0217	0.0474
Filled grain number per panicle	0.7355	0.3821	-0.0869	0.0922	-0.1518
Filled grain percentage	0.1437	0.6635	-0.1691	-0.0898	-0.0237
Grain weight	0.0043	0.0552	0.0431	-0.0411	0.0928

CONCLUSIONS

In conclusion, significant cultivar, year and site effect on grain yield was observed. The grain yield was significantly and positively correlated to plant height, grain number m^{-2}, filled grain number per panicle, filled grain percentage and grain weight. Principal components analysis (PCA) suggested that grain number and filled grain number per panicle are critical parameters for grain yield determination. Overall, grain number and filled grain number per panicle are determinants of the grain yield for the inbred and hybrid rice cultivars grown in agro-climatic conditions of southern China.

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