LOCAL CLIMATE AFFECTS GROWTH AND GRAIN PRODUCTIVITY OF PRECISION HILL-DIRECT-SEEDED RICE IN SOUTH CHINA

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Abstract. Temperature fluctuations at critical growth stages of rice may cause crop yield loss, shifts in crop growth periods as well as in sowing and harvesting times. Direct seeded rice has been proved as a the best alternative to transplanted rice and has been adopted successfully in many regions over the globe. This study was carried out to evaluate the productivity of rice sown under different environments with precision hill-direct-seeding method. Four rice varieties viz. Peizataifeng, Yuxiangyouzhan, Huahang 31 and Huayou 213 were sown in 6 different environments (E1-E6) by following split-plot design with four replications. Results showed that environments (E), varieties (V) and their interactions (E × V) significantly ($p \leq 0.01$) affected seedling survival rate, grain yield and yield related traits like panicles m^{-2}, spikelets panicle^{-1} ($p \leq 0.05$), fully filled grain % , 1000-grain weight, harvest index as well as daily dry matter and grain productivity. Differential varietal response under different environments depicted that all environments remained productive regarding rice growth and yield except environment 3 (E3) that caused grain yield reduction up to 45.86%. The overall performance and yield response of rice varieties under different environments was recorded as: *Huahang 31 > Yuxiangyouzhan > Peizataifeng > Huayou 213.* Further, correlation analysis showed significant and positive relationships of rice grain yield with yield contributing factors ($r > 0.47$) except panicles m^{-2} and grains panicle^{-1}. Hence, fluctuations in regional/local climatic conditions may cause shifts in sowing/planting times, poor stand establishment and seedlings survival rates that may lead to yield penalty in rice.

Keywords: *environment, growth, rice cultivars, temperature fluctuations, yield*

Introduction

Rice is one of the world’s most important cereal and a major food for more than half of the global population (Farooq et al., 2011; Krishnan et al., 2011; Ashraf et al., 2014).

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In China, more than 65% population solely relies on rice that serves as staple food (Zhang et al., 2005; Mo et al., 2016a). So for maintaining food security in China and to save the world population from hunger, it is necessary to increase the rice productivity by adopting better management strategies (Fang and Cheng, 2009; Ashraf et al., 2015). In general, about 0.6 to 0.9% increase in rice production per annum is required to meet the consumption rate of increasing population worldwide (Carriger and Vallee, 2007). On the other hand an increase of crop productivity per unit of land area is needed due to the effects of urbanization and industrialization on agricultural lands (Takai et al., 2006).

Climate change is one of the external factors that affect crop productivity worldwide, and may have significant impacts on growth and yield formation of rice. Predictions about climate change through general circulation models warrant an increase in global temperature of 4 ºC by the end of 21st century (IPCC, 2007) which confirms that future rice production will be in warmer climate.

Thus, adjustment of crop planting dates is an important strategy to avoid the effects of environmental severities in order to maintain crop growth and productivity (Sacks et al., 2010; Yao et al., 2011). Sowing dates affect rice growth duration, thus affecting rice response to light, temperature and other environmental factors (Wang et al., 2001a; Wang et al., 2001b; Yao et al., 2012; Ehsanullah et al., 2014). Low temperature in spring is the main factor that affects sowing date of direct seeding rice, for example, sowing too early may result in low temperature stress, whilst late sowing may face difficulty in the coordination of temperature and light growth period and ultimately the productivity of rice (Yi et al., 2010). The suitable temperature indices to get higher paddy yields during early-season rice in Guangdong province (China) are as follows: whole growth period is 23-24 °C, whereas from germination → tillering → booting → heading → physiological maturity are 18-21 °C, 21-25 °C, 24-28 °C and 27-30 °C, respectively (Wang et al., 2012). It has also been reported that rice should be sown earlier in Guangdong early-season rice cropping systems than their normal sowing (most probably in early March) in the fields due to the variable rainfall pattern and temperature fluctuations caused by a special climatic character of this region called “*Dragon Boat Water*” (Chen et al., 2006; Chen et al., 2010; Huang et al., 2011; Wang, Chen and Huang, 2011; Li et al., 2016).

Precision hill-direct-seeding of rice is a new planting technique developed by Luo et al. (2007) which has been used in China and some other countries in Asia (Kargbo et al., 2016). It showed advantages when compared to manual transplanting of rice nursery in the field and/or manual direct seeding (Luo et al., 2008; Tang et al., 2009). Moreover, precision hill-direct-seeding of rice requires optimal climatic conditions in the field, especially suitable temperature. In the best of our knowledge, to date, no experimental proof has yet been reported on the effects of different temperature regimes on seedling survival rate, growth and yield of precision hill-direct-seeded rice in the agro-climatic conditions of South China. Therefore, we have conducted a field experiment with four popularized rice cultivars sown under six different environments to study their effects on rice seedling survival rate, yield and yield components of precision hill-direct-seeded rice under local climatic conditions of the Guangdong province of South China where temperature fluctuations (low at early seedling establishment phase and high at flowering and grain filling stage) limits rice growth and productivity. The main objective of this study was to ascertain the impacts of changes in the local climatic conditions on the performance and yield formation of rice under field conditions.

Materials and methods

The field experiment was conducted at Experimental Research Farm, College of Agriculture, South China Agricultural University, Guangzhou (23°09′N, 113°22′E and 11 m above the sea level), Guangdong Province, P. R. China, during 2011. The experimental soil was sandy loam soil with following properties: soil pH = 5.44; organic matter = 19.65g kg^{-1}, total nitrogen = 0.97g kg^{-1}, available phosphorus = 31.74 mg kg^{-1}, available potassium = 189.48 mg kg^{-1}. This region has a humid subtropical monsoonal climate with warm winters and hot summers with an annual average temperature range lies between 21 to 29 °C (Mo et al., 2016b). Four popularized rice cultivars of this region i.e., *Peizataifeng*, *Yuxiangyouzhan*, *Huahang 31* and *Huayou 213* with 125-130 days of growth were obtained from College of Agriculture, South China Agricultural University Guagzhou, China. Among these cultivars, *Peizataifeng* and *Huayou213* were hybrid rice, whereas *Yuxiangyouzhan* and *Huahang 31* were inbred rice.

Field preparation and crop management practices were followed according to the standard practices for this region (Tang et al., 2008). Before sowing, field was fully irrigated and then cultivated with tractor-mounted cultivator thrice, and two days later raked with laser land leveling machine. Seeds of all four rice cultivars were sown on 6 different dates (*Table 1*) using a precision hill-direct-seeding machine (2BD-10) at spacing of (35 cm + 15 cm) × 14 cm with a seed rate of 15 kg ha^{-1} in the well prepared land by following split-plot design with four replications. The meteorological data regarding temperature range and relative humidity during the whole rice growing season has been shown in *Figure 1*. ‘Super rice special fertilizer’ 1200kg ha^{-1} (N 12.5%, P_2O_5 6.0%, K_2O 10.0%, organic matter 15.0%) was applied 25 days after sowing. Mature crop was harvested on 10th and 15th July to record paddy yield and harvest index. Standard agronomic practices were followed with respect to irrigation, pest management, and weed control as recommended by the Guangdong Province, South China.

Table 1. *Development of four rice cultivars as affected by a wide range of environmental conditions*

Environments	Sowing dates	Dates of 50% flowering	Days to harvest	Mean max./min./ Avg. temperature (°C) [a]	Mean max./min./ Avg. temperature (°C) [b]
E1	24-Feb	2-Jun	137	25.7/15.3/18.9	33.2/23.7/27.9
E2	1-Mar	6-Jun	132	22.0/13.4/16.9	33.5/25.6/28.9
E3	5-Mar	9-Jun	132	17.7/12.9/14.8	32.8/25.8/28.7
E4	10-Mar	11-Jun	127	22.5/13.4/17.0	32.6/25.5/28.5
E5	15-Mar	12-Jun	122	17.4/11.9/14.2	32.3/25.5/28.3
E6	20-Mar	12-Jun	117	20.3/13.9/16.3	32.3/25.5/28.3

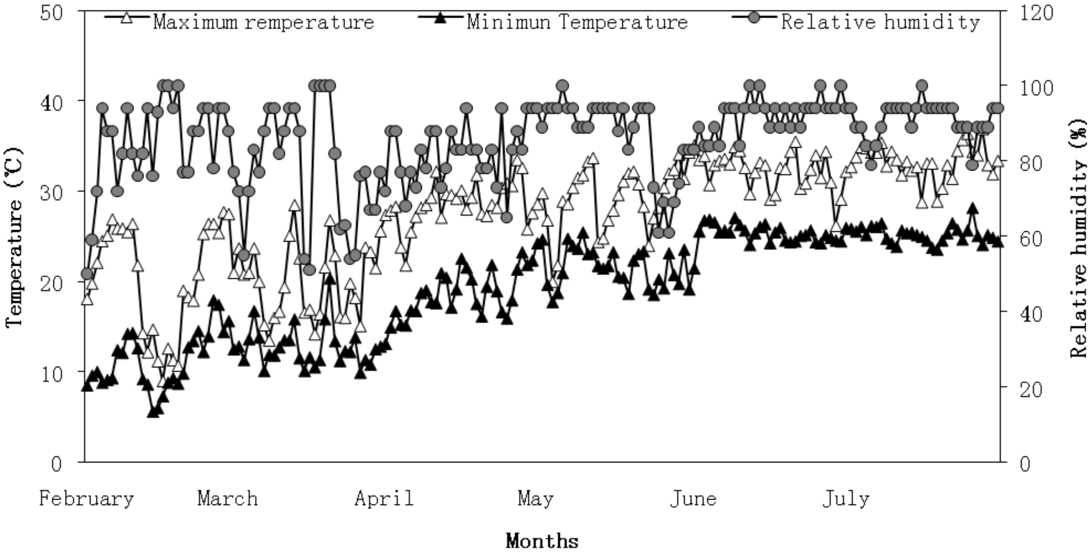

Figure 1. *Daily maximum and minimum temperature (°C) and relative humidity (%) during the course of study*

Seed number were counted immediately from a randomly selected unit area (1 m^2) at four different locations in each plot after sowing and recorded by marking each location; the survival seedling number was counted at each marked location at the four leaf stage to calculate the seedling survival rate by following formula: (survived seedlings / total rice seedlings) × 100.

At maturity, four hills were uprooted randomly, oven-dried at 70 °C till constant weight to determine of rice dry biomass. Panicle numbers were counted from a randomly selected unit area (1 m^2) at four different locations in each plot then averaged. Five hills were randomly selected from each plot to calculate total spikelets per panicle, grains per panicle and fully filled grain percentage. Five samples of thousand grains were taken randomly from each seed lot, weighed and averaged to record 1000-grain weight. One unit area (1 m^2) of plants was harvested, threshed manually, sun dried, weighed and then adjusted to 14% moisture content to recorded grain yield.

Harvest index (HI) was calculated as: (grain yield/biological yield) × 100. Daily grain and dry matter productivity was calculated as the ratio between grain yield and dry matter accumulation at maturity to whole crop growth period and expressed in kg grain per hectare per day and kg dry weight per hectare per day (kg ha^{-1} d^{-1}), respectively.

A split plot design with a plot size of 30 m^2 was followed in which sowing dates and cultivars were randomized in main and subplots, respectively with four replications. Statistical analyses were performed using analysis of variance (ANOVA) by using Statistix 8 (Analytical software, Tallahassee, FL, USA). The differences amongst treatments were separated using least significant difference at the 5% probability level. Figures were generated by using Microsoft Excel 2007.

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Results

After seed sowing, the highest values for mean maximum temperature were recorded in E1 while lowest values for mean maximum, minimum and average temperatures were recorded in E5 environment (*Table 1*). Days to 2-leaves stage in rice seedlings for E2 was exposed to temperatures less than 12 °C (around March 15) (*Fig. 1; Table 1*). Days to 50% flowering were shorter with late sowing (E5 and E6) than with early sowing (*Table 1*). Besides, days to harvest were shorter with late sowing than with early sowing, excluding a similar growth period in E2 and E3. The environment from E2 to E3, i.e., from March 2 to March 5 sowing seems to be the environment period that separated the six environments into the two ranges of environments. The mean maximum, minimum and average temperature of 50% flowering were in the range of 32.3-33.5 °C, 23.7-25.8 °C and 27.9-28.9 °C, respectively. However, high temperatures (~35 °C) were observed in E3 (June 9) environment (*Fig.1*). Grain yield was significantly different for environments, variety their interaction (E × V) (*Table 2*). Among six different environments, E6 on average produced the highest grain yield, with E1-E5 affected by cooler temperature during seedling stage, and/or higher temperature during flowering and/or grain filling stage, resulting in significantly lower grain yields. For rice varieties, maximum and minimum grain yield was obtained for *Huahang 31* (6.75 t ha^{-1}) and *Huayou 213* (4.75 t ha^{-1}), respectively (*Fig. 3a*).

Table 2. *Effect of growing environment on grain yield, yield related traits, seedling survival rate and productivity of rice among varieties in terms of F-value*

Traits measured	**Environment（E）**	**Variety （V）**	**E × V**
Grain yield	2457.78**	138.86**	16.13**
Panicle number per m^2	6.15**	9.45**	3.11**
Number of spikelets per panicle	3.22*	14.27**	2.85**
Fully filled grain percentage	26.36**	15.28**	2.82**
1000-grain weight	437.26**	242.52**	92.19**
Seedling survival rate	82.51**	8.99**	12.72**
Daily dry matter productivity	48.89**	6.02**	5.28**
Daily grain productivity	3673.68**	137.33**	16.56**
Harvest index	4.67**	25.50**	8.75**

Date with no asterisk were non-significant, * and ** mean significance at the 0.05 and 0.01 probability level, respectively

Yield related traits, seedling survival rate and productivity of rice varied significantly among varieties, environment, and E × V interactions (*Table 2*). Overall, maximum temperature had significant and positive effects on all yield related traits, seedling survival rate and productivity of rice except for number of grains per panicle and harvest index. Across environmental analysis revealed that low seedling survival rate in E2 and E3 (due to low temperature at this stage, especially at 2 leaf stage) than other environments led to reduced panicle number per m^2 (*Fig. 1, 2c and 3a*). Moreover, the maximum (76.13%) and the minimum (31.33%) seedling survival rate were recorded at E5 and E1, respectively (*Fig. 3a*). Grain filling percentage was affected by high temperature during E2-E4, which resulted in significant reduction in grain filling % than other environments (*Table 1, Fig. 2b*). On average, E6 exhibited the highest daily grain and dry matter productivity (62.80 and 151.05 kg ha^{-1} d^{-1}, respectively) than other environments, while E3 was observed to decline in grain and dry matter productivity by 30.14 and 86.68 kg ha^{-1} d^{-1}, respectively. Furthermore, values for daily grain (37.47 to 53.02 kg ha^{-1} d^{-1}) and dry matter (109.23 to 119.86 kg ha^{-1} d^{-1}) were recorded in both inbred and hybrid rice cultivars (*Fig. 3b and d*). Further, *Huahang 31* and *Yuxiangyouzha* produced higher grain yield while substantial decrease in grain filling percentage was observed in *Peizataifeng* and *Huayou 213* and reduced grain number per panicle in E3. Additionally, both E1 and E6 had 42.77% and 41.93% higher harvest index, respectively as compared to other environments. Among rice varieties, the highest harvest index was recorded in the following order: *Huahang 31* (53.02%) > *Yuxiangyouzhan* (40.08%) > *Peizataifeng* (36.28%) > *Huayou 213* (34.93%) (*Fig. 3c*).

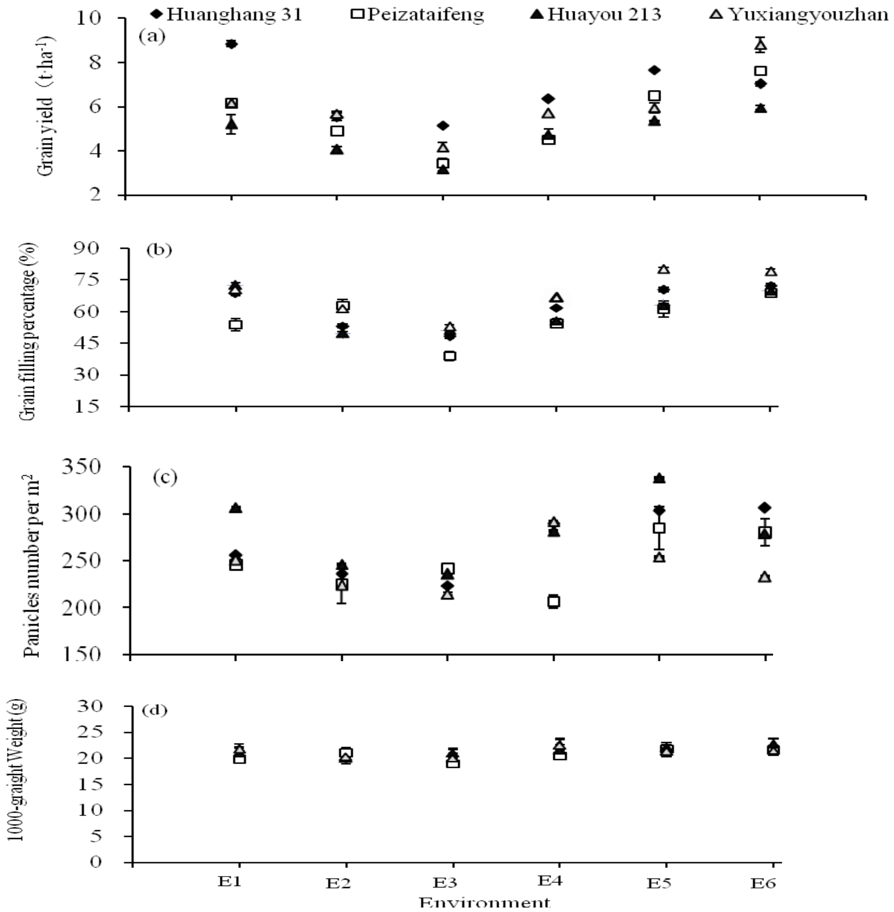

Figure 2. Effect of series of six different environments on (a) grain yield (t ha^{-1}), (b) grain filling %, (c) panicles number per m^2, (d) 1000-grain weight (g) of four different rice cultivars. Capped bars indicate means of three replicates ± SE.

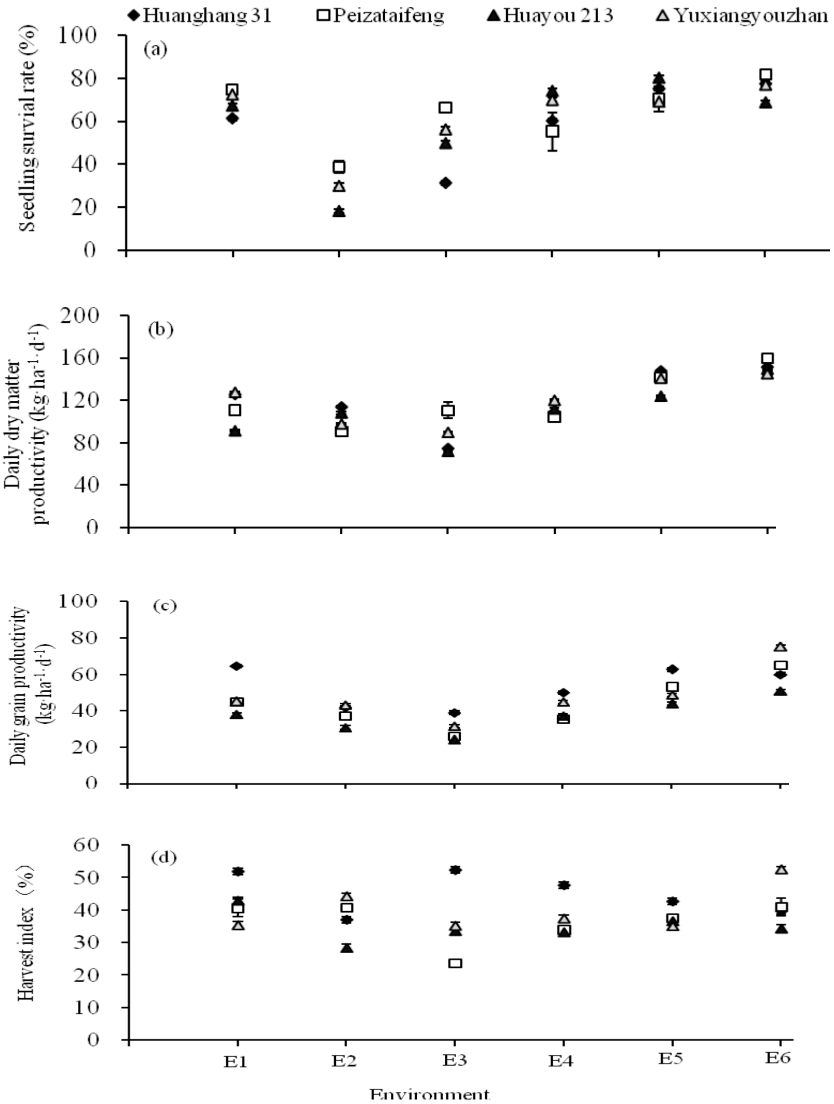

Figure 3. *Effect of series of 6 different environments on (a) seedling survival rate (%), (b) daily dry matter productivity (kg ha^{-1} d^{-1}), (c) harvest index (%), (d) daily grain productivity (kg ha^{-1} d^{-1}) of four different rice cultivars. Capped bars indicate means of three replicates ± SE.*

Correlation analysis depicted that grain yield significantly and positively correlated with filled grain % ($r = 0.722$), 1000-grain weight ($r = 0.478$), daily grain productivity ($r = 0.978$), dry matter accumulation ($r = 0.718$), harvest index ($r = 0. 692$) and daily dry matter productivity ($r = 0.703$), however, panicles m^{-2} and grains panicle^{-1} were remained non-significant regarding grain yield ($r = 0.303$ and $r = 0.115$), respectively. Furthermore, panicles m^{-2} was negatively correlated with grain panicle^{-1} while grains panicle^{-1} also showed a negative correlation with filled grain %, 1000-grain weight, dry matter accumulation and daily dry matter productivity (*Table 3*).

Table 3. *Correlation analyses for seedling survival rate, grain yield, yield related traits and productivity of rice among varieties and treatments*

Traits	Grain yield	Panicles number per m^2	Grains per panicle	Filled grain percentage	1000-grain weight	Daily grain productivity	Dry matter accumulation	Harvest index	Daily dry matter productivity
Grain yield	1								
Panicles number per m^2	0.303	1							
Number of grains per panicle	0.115	0.561**	1						
Filled grain percentage	0.722**	0.425*	–0.128	1					
1000-grain weight	0.478*	0.649**	–0.365	0.641**	1				
Daily grain productivity	0.978**	0.351	0.069	0.746**	0.542**	1			
Dry matter accumulation	0.718**	0.450*	–0.013	0.604**	0.424*	0.753**	1		
Harvest index	0.692**	0.019	0.191	0.431*	0.285	0.627**	0.009	1	
Daily dry matter productivity	0.703**	0.485*	–0.064	0.633**	0.510*	0.784**	0.969**	0.023	1

*Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$; values without asterisks are non-significant at both $p \leq 0.01$; $p \leq 0.05$

Discussion

Enhancing grain yield has long been a main purpose of rice researchers to meet the needs of increasing population; however climate change threatens to decrease the crop productivity. In the process of rice yield formation, rice growth period is confronted with different light and temperature conditions. Differences in sowing dates might result in changed growth periods thereby affecting plant biomass accumulation through altering the length of photosynthetic time (Yao et al., 2012). Thus, sowing dates affect grain yield by influencing the whole rice growing process. Sowing or planting dates for crops like rice, wheat, maize etc. were studied worldwide in coping with global climate change or for gaining high yield and quality (Sacks et al., 2010; Yao et al., 2011; Hussain et al., 2012). Sowing dates significantly affected the seedling survival rate, grain yield, yield related traits and rice productivity of plants growing in different environments (*Table 2*). Similarly, Sun et al. (2012) reported a significant effect of sowing dates on yield and some yield related traits (spikelets and seed setting rate) under low-light stress at heading stage. E1 and E6 supposed to increase yield due to increase in panicle number per m^2, fully filled grain percentage and 1000-grain weight, yet different rice varieties performed differently in this connection *(Fig. 2).*

Grain yield productivity on each sowing date (E1 to E6) was 48.14 kg ha^{-1} d^{-1}, 38.21 kg ha^{-1} d^{-1}, 30.14 kg ha^{-1} d^{-1}, 41.86 kg ha^{-1} d^{-1}, 52.16 kg ha^{-1} d^{-1} and 62.80 kg ha^{-1} d^{-1}, respectively (*Fig. 3d*). Thus, an increase in rice yield by more than 30.14 kg ha^{-1} d^{-1} for each day may be achieved, if rice sowing was earlier before and after E3. Rice sown on both E2 and E3 had a lower seedling survival rate due to extensive low temperature which caused a gradual reduction in panicle number per m^2 (*Fig. 2c*). Higher grain filling percentage and 1000-grain weight was observed on rice sown earlier before E3 and might be due to prolonged rice photosynthesis time in early sowing and warmer climate in late sowing enjoyed by crop resulting in higher daily dry matter productivity. Under delayed sowing, rice spikelet number per panicle and fully filled grain percentage decreased, and no difference in panicle and grain weight was noticed (Yao et al., 2010, 2011; Huo et al., 2012; Abid et al., 2015). Shorter rice photosynthesis time and higher temperature at panicle initiation stage might be the possible reasons for the fewer grain number per panicle, observed in late sowing environment (E4-E6). These findings corroborate with Chen et al. (2003) who argued that in single-season rice, delayed sowing reduced the grain number per panicle, but increased seed setting rate and 1000-grain weight, improved late leaf area index, increased photosynthetic products and improved rice quality. In Philippines, Peng et al. (2004) observed 10% reduction in paddy yield for each unit rise in minimum temperature limits during one-season of rice cultivation whereas rice yield variability and poor seed quality due to extreme temperatures at reproductive stage was also reported by Martínezeixarch and Eills (2015).

All rice cultivars were remained significantly different for seedling survival rate, grain yield, and yield related traits and rice productivity (*Table 2*). Variation in grain yield and other parameters for different rice genotypes might be due to their genetic diversity and morphological characters (Yang et al., 2007; Shahidullah et al., 2009; Ashfaq et al., 2012). Higher grain yield recorded in rice variety *Huahang 31* (6.75 t ha^{-1}) might be attributed to higher yield related traits (panicle number per m^2 and 1000-grain weight) *(Fig. 2)*, daily dry matter productivity and harvest index (*Fig. 3b and c*). *Yuxiangyouzhan* had a higher grain number per panicle, grain filling percentage and daily dry matter productivity, but reduced panicles per m^2, 1000-grain weight and harvest index led to lower grain yield than *Huanghang 31*. The lowest grain yield was noted in *Huayou 213* due to the reduction in yield related traits (except panicles per m^2), daily dry matter productivity and harvested index (*Fig. 2 and 3*).

E × V interaction had significant effect on rice yield, yield related traits and other parameters (*Table 1*). *Huahang 31* and *Yuxiangyouzhan* (sown on 24th February and 20th March, respectively) provided higher grain yield that might be due to higher dry matter productivity and harvest index in both these cultivars (*Fig. 2 and 3*). The substantial decrease in grain filling percentage observed in *Peizataifeng* and *Huayou 213* in E3 (sown on March 5) and along with reduced grain number per panicle observed in *Huayou 213* in E3 (sown on March 5) resulted in minimum grain yield in both these cultivars. Genetic variations among rice varieties might also be responsible for differential response regarding grain yield, dry matter accumulation and harvest index under the same or different environmental conditions (Yao et al., 2010). For instance, delayed sowing resulted in yield decline due to reduced spikelet number per panicle and seed setting rate, but degree of yield reduction was different among different rice varieties (Nagarajan et al., 2010). Similarly, differential yield response and environmental sensitivity of different rice cultivars under different environments was also reported by Wang et al. (2001). We further found that different rice varieties produced different yields for E × V interaction which indicates a strong relationship among local climatic conditions including temperature fluctuations, photosynthetic and respiratory activities of plants and yield formation and other morpho-physiological and biochemical mechanisms that affect growth and productivity of rice.

Conclusion

Conclusively, among all environments, only E3 caused yield reduction by 30.14 kg ha^{-1} d^{-1}. Compared to other environments, the grain yield declined by 14.45- 45.86% in E3, however, different rice varieties performed differently in this regard. Hence, the entire environment was considered favorable for rice production in Guangdong province (China) except for E3.

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