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INVESTIGATING THE RESPONSE MECHANISMS OF IRRIGATED RICE (*Oryza sativa* L.) UNDER VARYING MID- HIGH-LATITUDES OF NORTHEAST CHINA AIMING BETTER FUTURE ADAPTATION

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ABSTRACT

Climatic variabilities in China make the rice vulnerable, which increase the problems due to adverse impacts on planting area and productivity especially in Northeast China (NEC). Four cultivars (late-maturing; Longdao-18, Longdao-21, early-maturing; Longjing-21, Suijing-18) under RCBD design were selected at Harbin and Qiqihar during 2017 and 2018. Time to reach maximum-filling of superior and inferior grains showed significant differences under varying environments which influenced the filling-rates and dry-weights more obviously in early-maturing cultivars over late-maturing. Maximum grain-filling was observed during middle of filling-period about 60% at Harbin whereas during late period at Qiqihar. Across all cultivars and sites, 3/4th of variation in time of maximum anthesis might be attributed with atmospheric temperature change especially Tmin during a week preceding specific anthesis event. High temperature on earlier anthesis during start of day promoted escape from high-temperature stress later during the day. Higher vapor pressure deficit delayed anthesis and ultimately shortened grain-filling.

Keywords: Climate change, self-adaptability, anthesis, grain-filling, Northeast China

INTRODUCTION

Northern boundary in China has been expanded up to 43°N latitude in the past few decades due to obvious climate warming, now Heilongjiang province has become one of the largest rice-producing regions in China quadrupling the area under rice cultivation (GAO & LIU, 2011). As it is very likely to have wide-ranging impacts of climate variability on environment, agriculture, socioeconomic and other related sectors. It is of great concern in high-latitude regions like Northeast China (NEC) to have the effective and sound adaptive measures for agriculture systems against climate change especially considering the adaptability mechanisms of crops to local climate change trends and variability.

Global mean surface temperatures are expected to increase from the present by 1–3°C by the year 2100 (IPCC 2014). Considering the climate changes in the last hundred years, China’s climate has generally become warmer and drier (PIAO et al., 2010). Over the last century, Northeast China (NEC) is one of the areas experiencing climatic fluctuations especially evident warming (LIU et al., 2005). The mean surface temperature has increased by 1.71℃ in NEC since 1950, and it has been projected to increase about 1.0℃ by 2030 (LIU et al., 2010). Temperatures were higher in the 1920s, then lower in the 1950s and higher again in the 1970s-1980s (MASUTOMI et al., 2009). The daily minimum temperature rose more strongly than the daily maximum temperature, which markedly narrowed the diurnal temperature range (ASSENG et al., 2015). The annual average precipitation has been decreasing since 1965 (LIU et al., 2005). The semi-arid areas in NEC are more vulnerable to drought stress.

In recent decades, the rice area and production for NEC increased because of warming trends (MASUTOMI et al., 2009). Hu et al. (2019); Lv et al. (2018) reported that rice yield firstly would continue to increase until 2030 and then it will start to decline in NEC. Rice area expanded and production increased significantly during 1980–2010, due to increased amendments of agricultural inputs in the past three decades (HU et al., 2019). There was a small quantity of paddy rice fields about 3479km^2 back in 1958 which accounted for 0.77% of the Heilongjiang’s territory. However, this quantity increased annually at rate of 504 km^2 and more than quadrupled to 14564 km^2 by 1980 because of warming (GAO & LIU, 2011). Most of paddy rice fields were concentrated between the isolines of 2 and 3°C in southern Heilongjiang by 1958 (GAO & LIU, 2011). Obviously, the paddy rice fields expanded outward by following closely the pattern of climate warming. It has been found that rice cultivation area expanded by approximately 2.4×10^6 ha during 1984-2013 at an annual incremental rate of 8.0×10^4 ha (LI et al., 2017). All this expansion happened because of warming which accounted for 98% and no decline in rice area was noticed. There was a drastic change in rice production from 1961-2010 because of frequent periods of cold stress, when the growing season temperature was less than 12°C (ZHANG et al., 2015; ROSENZWEIG et al., 2014). There is a mutually influential and complex relationship between land cover and climate change (ZHAO et al., 2001; RAO et al., 2014). It can be said that climate warming can dictate the type of land cover change permissible in a geographic region (REID et al., 2000; PITMAN et al., 2004).

Cultivation of rice, because of its high-input requirements has been threatened and vulnerable due to climate change particularly prolonged climate stresses (RABARA et al., 2014). High temperature stress speed-up the plant developmental processes which shorten the period of yield production (YAO et al., 2007; KRISHNAn et al., 2011; WASSMANN et al., 2009). Demonstration by spikelet sterility in response to high temperature stress because of reduction in assimilate accumulation that leads to irreversible losses (KORRES et al., 2017). Higher temperature stress can reduce the germination ability of rice which reduces the plant height, tiller number and dry weight of grains (WASSMANN et al., 2009). High temperature interruptions at anthesis on heat intolerant cultivars cause the failure to dehisce (KOBAYASI et al., 2010). Low temperature stress, if prevails during the anthesis, then it will cause spikelet infertility in rice, reduces the high production potential of cultivar and ultimately leading to reduced stability of final grain yield (ZENG et al., 2017). Previous studies have reported that cold stress was one of the main problems in past for NEC to limits rice production because it shortens anther dehiscence, produce poor pollens, and reduced pollen germination on stigma (PRASAD et al., 2006). Unsteadiness in climatic conditions for example decrease in diurnal temperature range if keep happening then it would be harmful for rice sustainability, due to the asymmetric effects of minimum and maximum temperatures (TAO et al., 2006). Because of climate change extreme events following changes may occur in Heilongjiang province of NEC in future; the areas currently under cultivation, their northern boundary will move further west as well as north (ZHANG et al., 2015), and the crop maturity time will change from early to mid and late maturity due to the longer growing period.

In previous studies, at NEC just assumed and focused with convenience to compare simulated rice yields under future climate scenarios with those for the current climate. Later, it was realized that such assumptions were not practicable, and need further analysis of adaptation practices against response mechanism of crop e.g., adjustment of sowing dates (BASSU et al., 2009), use of new crop cultivars with shorter or longer growing seasons respective to the growing region (OLESEN et al., 2000), changes in cropping systems and other management practices as adjustments (TUBIELLO et al., 2000). For NEC most of the studies were conducted related to geographic variation of climate change and impacts on rice productivity but no sound adaptation measures were specified as short-term adaptations. Various studies have reported that for future sustainability of rice under changing climate in NEC sound adaptive measures are required (LOBELL et al., 2008) as adjustments of cropping systems and cropping patterns against climatic fluctuations (NJIE et al., 2009; WANG et al., 2014). The current cultivation methods and cropping systems are generally suited to the current climate. However, with a fluctuating climate, the current cultivation methods, cropping systems, and cultivars more likely may not match the changed environments. It has been indicated that if local farmers at NEC are being guided through adjustments mechanism for cropping patterns, it would be an adaptation measure to climate change (LIU et al., 2016). It is a rational choice for agricultural sustainability development and a food security strategy at regional scale. In general, the warming scenarios and fluctuations in climate may bring more opportunities than risks for food security and crop cultivation in China if adaptation measures would be taken regionally (CHEN et al., 2018). So, based on all these, the objectives of the current study are; investigating the growth and yield adaptability mechanisms of Japonica rice cultivars to different climate conditions; better apprehension of self-adaptability and theoretical adaptation mechanism; filtering the potential possible adjustive measures in management practices to Japonica rice system against climate variability in NEC.

MATERIAL AND METHODS

Rationale and study area description

Major featuring rationale for this study is to comprehend the response mechanisms of the same rice cultivars under different climatic conditions, i.e., changes in eco-physiology to climatic variability. Moreover, understanding the self-adaptability of rice cultivars is a basis for proper outside intervention and adjustive measures, for example, crop variety layout planning, irrigation management etc. To evaluate the sound adaptation measures against climate stresses in NEC, its better firstly to analyze the adaptability mechanisms of Japonica rice cultivars to different climate conditions. Therefore, this study was conducted in one of the three provinces of Northeast China renowned for rice cultivation named Heilongjiang province located between 121^{o}13`-135$^{o}$05`E in longitude and 43^{o}22`-53$^{o}$24`N latitude with a continental monsoon climate. After decades of land reclamation, Heilongjiang has become one of the most important bases of agricultural products. Two regions were select from this province for this study i.e., Harbin, capital city of Heilongjiang and the other was Qiqihar. The mean annual temperature is 3.2℃ at Harbin, the mean annual frost-free season is 130 days, and the annual precipitation is 400–600 mm. Winters are dry and freezing cold here, but in January 24 hours average temperature is 17.6 °C. Spring and autumn constitute brief transition periods with variable wind directions. Summers can be hot, with a July mean temperature of 23.1°C. Qiqihar has a cold, monsoon-influenced, humid continental climate. It has long, bitterly cold, but dry winters, with a 24-hour average in January of −18.6°C. The annual mean Temperature is 3.95 °C. Spring and fall are mild, but short and quick transitions. Summers are very warm and humid, with a 24-hour average in July of 23.2°C. The average annual precipitation is 415 mm. Figure 1 is depicting the location of study regions on the map of China.

Data source

The experiment was conducted during the rice growing seasons in 2017 and 2018. Different cultivars were selected to check the impacts of varying climate; therefore, same cultivars were sown in different climatic regions of Heilongjiang province i.e., Harbin and Qiqihar. Design of the study was a randomized complete block design (RCBD) with three replicates. Nitrogen (N), Phosphorus (P) and potash (K) were amended as basal dose at recommended rate (90-60-60 kg ha^{-1}). The source used for N-fertilizer was synthetic Urea (46% N) and the compost made of poultry and manures (1% N), whereas the source used for application of P was synthetic diammonium phosphate (DAP). The N and P supplied from compost was also calculated. The remainder of required P and K was amended as basal dose using synthetic sources. The compost was incorporated as the basal dose, and the remainder N was fulfilled from synthetic Urea in three equal splits viz. basal amendment, at active tillering and panicle initiation. Four cultivars were selected for both sites Longdao-18, Longdao-21 (late-maturing), Longjing-21, Suijing-18 (early-maturing) to assess the response mechanisms of these Japonica rice cultivars to different climatic conditions and then to give adaptation measures. These cultivars were selected because of high adaptation locally in NEC, due to varying strength against climatic stresses, and due to difference in growing durations.

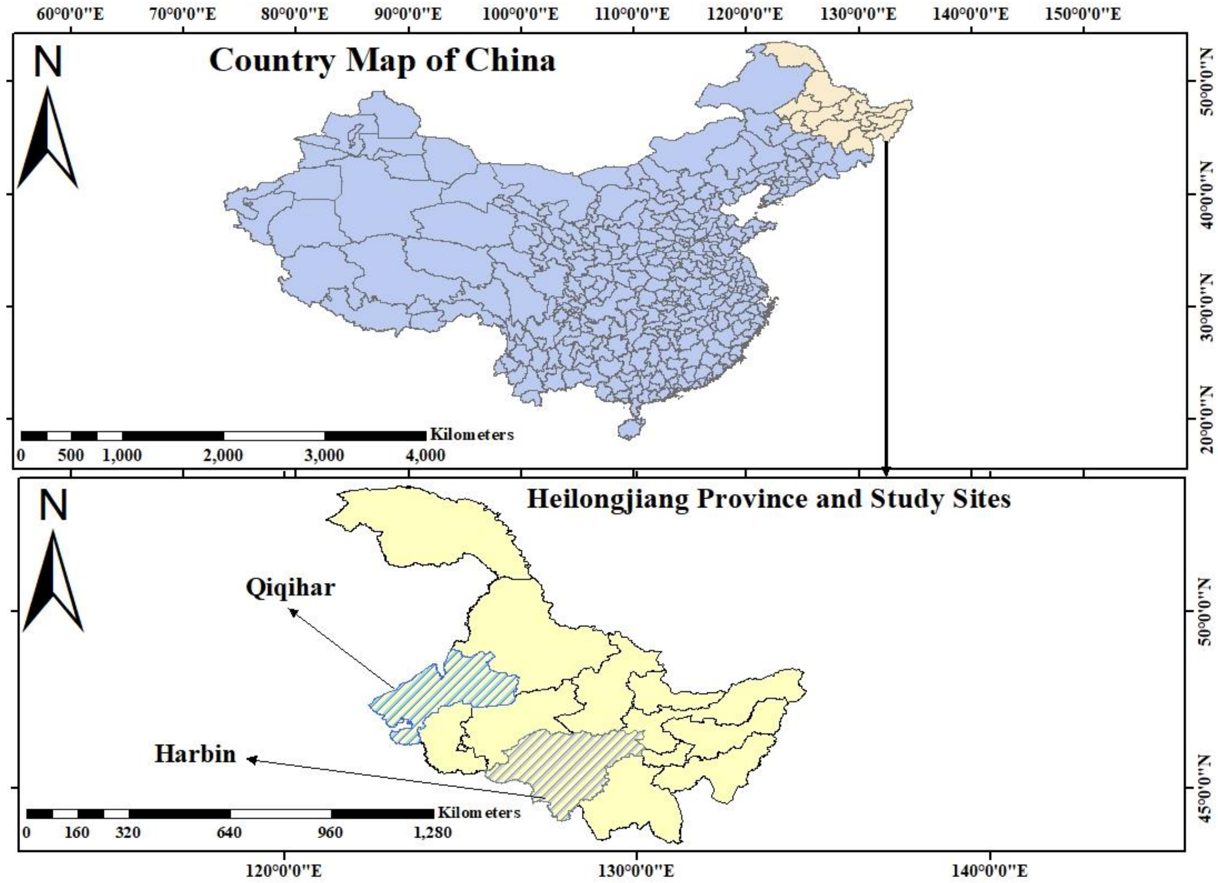

Figure 1. Country map of China and study sites (Harbin & Qiqihar) location in Heilongjiang province of NEC.

Crop data

For calculation of leaf area index (LAI) manual destructive method was used. Leaf area to land area ratio is termed as leaf area index. Leaf area was calculated at four growth stages tillering, booting, heading and maturity. Crop growth rate (CGR) was calculated by recording the dry biomass at same four growth stages selected for LAI. Hunt, in 1978, gave following formula for the calculation of CGR.

$$CGR = \frac{W2 - W1}{t2 - t1}$$

Where, W_2 and W_1 are the dry biomass weight at respective two growth stages and t_1 and t_2 is the time difference between these two stages.

Considering agronomic and yield parameters, average plant height was recorded at different growth and maturity stages by randomly selecting the 100 × 100 cm area in every plot. Average number of productive tillers per plant were counted by randomly selecting the 1m^2 in every plot. For calculation of number of branches and grains per panicle, 10 panicles of primary tillers were selected randomly from each plot and then the average was taken by calculating the number of grains and branches per panicle. 1000-grain weight was calculated by randomly taking 1000-grains three times and average was taken for each plot. The final grain yield was calculated after threshing the crop which was done at 14% moisture contents. Record for time taken by a specific growth stage was also calculated which is termed as Phenological record. For both sites, phenological record was measured at sowing, transplanting, tillering, booting, heading, grain filling and maturity stages. For calculation of grain filling rate, each plot was labeled with about 200 panicles, and the date of the day was 0 days. Samples were taken at 1 d, 4 d, 8 d, 12 d, 16 d, 20 d, 26 d, 32 d, 38 d, and 44 d after labeling. Total 10 spikes were taken every time, the superior and inferior grains were separated and counted (the superior grains, the grains of the three primary branches directly at the top; and the inferior grains, three at the bottom of the panicles). After that superior and inferior grains separately were dried and recorded the dry weights for each plot. The dried grains were weighed after artificially stripping of hulls and fitted using the Richards growth equation referenced to (Zhu Qingsen 1988);

$$W = A(1 + Be^{-kt})^{-1/N} \qquad \text{[i]}$$

Where W is the weight of grains (mg), A is the final grain weight, t is the time after flowering in days (d), and B, k, and N are equation coefficient parameters calculated after regression. Dry weight accumulation and grain-filling rate were recorded in “g grain^{-1}” and “g grain^{-1} day^{-1}. Moreover, the grain-filling rate was calculated as the derivative of the above equation [i].

$$G = AKBer^{-kt}/(1 + Be^{-kt})^{(N+1)/N} \qquad \text{[ii]}$$

In the formula, W is the grain weight (mg), A is denoted as the final grain weight (mg), t is designated as the time in days (d) after anthesis, and B, k, and N are the equation coefficients. For the calculation variation in time of day of anthesis as well duration of anthesis, a 1.0 m^2 area in each plot was selected as sub-plot. Every sub-plot was observed every day during the entire flowering phase every 30 min or less from sunrise until the end of the anthesis on the last spikelets about early afternoon or midday. Onset of anthesis, maximum anthesis and end of anthesis was observed to have the variation in time of day of anthesis to quantify environmental variability impacts on the time of day of anthesis and duration of anthesis, in order to enable better predictions and justifications of spikelet sterility risks (data not presented).

Meteorological data

Average daily weather parameters were recorded during the growth season of rice at both sites by manually installing the automated and computed weather station in experiments which was interlinked with the main weather station at both sites. Variation in weather parameters were calculated every five minutes. The meteorological data was measured during the growth season of average for both sites, maximum and minimum atmospheric temperature (°C), soil temperature (°C) at different depths, relative humidity (RH) (%), daily precipitation (mm), and daily radiation accumulation (MJ/m^2).

Statistical analysis

Duncan’s multiple range test (DMRT) was used to calculate the differences among cultivar and treatment means. For the analysis of variance (ANOVA), one-way ANOVA was applied through Tukey’s HSD test as well as Fisher’s ANOVA technique which calculated the specific differences among treatment means, but it did not depict which means are different. Thus, DMRT was applied to have clear differences between pairs of means. For the analysis of grain-filling rate (mg grain^{-1} day^{-1}) and grain weight accumulation (mg grain^{-1}), the dried grains were weighed after artificially stripping of hulls and were fitted using the Richards equation for calculation of necessary parameters to estimate the impact of climatic variability on grain-filling. The software “Statistix-8.1” was used to for the statistical analysis of the collected data, whereas “SigmaPlot-14.0” and “Microsoft Excel-2016” were used to draw the figures. For the mapping of the study sites, “ArcMap 10.6.1” software was used.

RESULTS AND DISCUSSION

Yield components data

Findings of this study indicate that the mean values regarding yield components were significantly different among cultivars within a site and the interaction between two sites was also significant. Discussing about plant height, maximum plant height was observed in Longdao-18 at both Harbin and Qiqihar sites viz. 105.6 cm and 113.5 cm, respectively, during rice growth season in 2018. Whereas, the mean values regarding plant height at both sites were less in 2017, given in

Table 1. Maximum panicle length was observed in Longdao-21 with the value of 22.6 cm followed by Longdao-18 at Harbin, whereas maximum panicle length was recorded in Longdao-18 with values of 21.3 cm followed by Longjing-21 as shown in table 1. This trend was same in year 2017 but the average values were less as compared to 2018 (table 1). According to the observed number of productive tillers which are more important in overall yield estimation rather than total tillers, the highest number per hill was observed in Suijing-18 at both sites Harbin and Qiqihar with mean values of 17 and 11, respectively, in 2017, whereas, similar results were seen with mean values of 15 and 11, respectively in 2018 (table 1). Mean values regarding grains/panicle were highest in Longdao-18 at Harbin and Qiqihar study regions with values of 152 and 158, respectively, but the trends varied with other cultivars e.g., Longjing-21 showed higher number of grains per panicle at Qiqihar region but at Harbin it produced a smaller number of grains with mean value of 106 during 2018, as given in table 1. The mean values for grain yield were highest in year 2018 than in 2017 in Longdao-18 at both sites and interaction was also significant between two sites, as the mean highest values were 9500 kg ha^{-1} and 13250 kg ha^{-1} at Harbin and Qiqihar, respectively given in table 1 during 2018, whereas in 2017 it was 11133 kg ha^{-1} and 9366 kg ha^{-1}, respectively which significantly less than 2018.

But here question comes that why there is a large difference, it might happen due to differences in prevailed environmental conditions during respective growth period at respective study region. The environment conditions during growth period in 2018 at Qiqihar was suitable than Harbin as there were so many rainfalls during the growth season though frequent rainfalls affected the anthesis period too. So, it can be concluded as the period during growth was wet season at Qiqihar. As the overall values about yield contributing parameters were highest in Longdao-18 as compared with other cultivars but this trend changed in 1000-grain weight during both seasons, 2017 and 2018. Maximum 1000-grain weight was recorded in cultivar Longjing-21 with value of 26.9 g in 2018 and in 2017 it was 25.8 g, and the interaction among varieties at Harbin was significant. Whereas the interaction among varieties at Qiqihar was non-significant as all the cultivars produced almost same 1000-grain weight but highest with little difference compared to other cultivars was recorded in Longdao-21 with value of 25.7 g, shown in table 1.

Table 1. Impacts of varying environmental conditions on yield and yield components of four different cultivars at Harbin and Qiqihar (PH: plant height; PL: panicle length; PT: productive tillers; GY: grain yield; 1000-GW: 1000-grain weight)

Site	**Cultivars**	**Year**	**PH (cm) mv ± sd[*] a[**]**	**PL (cm) mv ± sd**	**PT/hill mv ± sd**	**Grains/panicle mv ± sd**	**GY (kg ha^{-1}) mv ± sd**	**1000-GW (g) mv ± sd**
Harbin	Longdao-18	2017	105.6 ± 3.5 a	20.8 ± 0.7 b	14 ± 2 b	152 ± 15.0 a	9500 ± 400 a	23.5 ± 0.4 c
		2018	103.2 ± 3.0 a	21.5 ± 0.7 a	13 ± 2 b	146 ± 17.0 a	9367 ± 369 a	22.4 ± 0.4 b
	Longdao-21	2017	95.8 ± 4.2 c	22.6 ± 1.5 a	14 ± 1 bc	151 ± 23.0 a	9166 ± 289 a	23.7 ± 1.1 bc
		2018	93.4 ± 4.7 c	20.0 ± 1.4 b	12 ± 1 b	144 ± 27.0 a	9017 ± 283 a	22.9 ± 1.1 b
	Longjing-21	2017	96.7 ± 2.5 bc	17.4 ± 0.7 c	12 ± 1 c	106 ± 15.0 b	7166 ± 305 c	26.9 ± 0.8 a
		2018	95.0 ± 1.8 bc	16.3 ± 0.7 c	11 ± 1 c	101 ±14 a	7050 ± 296 c	25.8 ± 0.8 a
	Suijing-18	2017	100.0 ± 1.3 b	18.5 ± 0.6 c	17 ± 1 a	141 ± 8.0 a	8333 ± 208 b	25.2 ± 0.4 ab
		2018	98.1 ± 1.6 b	17.4 ± 0.6 c	15 ± 01 a	136 ± 7 b	8200 ± 176 b	24.1 ± 0.2 b
Qiqihar	Longdao-18	2017	113.5 ± 0.5 a	21.3 ± 1.0 a	10 ± 1 a	158 ± 4.0 a	13267 ± 351 a	25.2 ± 0.3
		2018	111.7 ± 0.4 a	20.5 ± 1.0 a	11 ± 1 a	154 ± 4.3 a	12267 ± 453 a	24.1 ± 0.6
	Longdao-21	2017	100.7 ± 0.7 b	20.1 ± 0.8 a	10 ± 2 a	150 ± 7.0 ab	13133 ± 350 a	25.7 ± 0.2
		2018	99.2 ± 0.56 b	19.8 ± 0.8 ab	11 ± 1 ab	153 ± 6.6 a	11133 ± 305 a	24.6 ± 0.1
	Longjing-21	2017	96.5 ± 0.5 c	20.9 ± 1.4 a	09 ± 1 a	132 ± 3.0 c	10500 ± 225 b	25.3 ± 0.4
		2018	94.6 ± 0.5 c	19.0 ± 1.4 ab	10 ± 1 ab	133 ± 3.5 b	9733 ± 208 b	24.1 ± 0.3
	Suijing-18	2017	94.5 ± 1.2 d	19.2 ± 0.3 a	11 ± 1 a	143 ± 8.0 bc	9700 ± 100 c	25.1 ± 0.3
		2018	94.1 ± 1.7 c	18.1 ± 0.4 b	10 ± 1 b	142 ± 8.5 ab	9634 ± 57 b	24.0 ± 0.2

([*]mean values ± standard deviation; [**]DMRT to differentiate the groups of means)

Variation in crop growth rate (CGR) (g m^{-2} day^{-1}) and lead area index (LAI)

One of the main aims of this research was to assess the impacts of different climate conditions on crop growth rate and leaf area index, because leaf area is the source to estimate how the crop is growing and what would be ultimate yield. The variation in leaf area indices for all cultivars for both sites during 2017 and 2018 is presented in figures 2A and 2B. The indicator of a crop's assimilatory system is leaf area index. Progressive increase in leaf area index was seen up to the end of grand growth stage. LAI increased but as the grain filling stage approached, LAI started to decrease for both sites. Maximum growth and maximum LAI were recorded in Longdao-21 at Harbin with value of 6.06 during 2018 but the decreasing trend during later growth stages was more rapid as compared to other cultivars as shown in figure 2B. Whereas, same trend was observed in Qiqihar where maximum LAI was also seen in Longdao-21 with mean value of 4.54 in 2018 and it was less in 2017 as shown in figure 2A. Overall, the values for LAI was higher at Harbin than in Qiqihar during both rice growing periods 2017 and 2018 which might be due to suitability of environmental conditions.

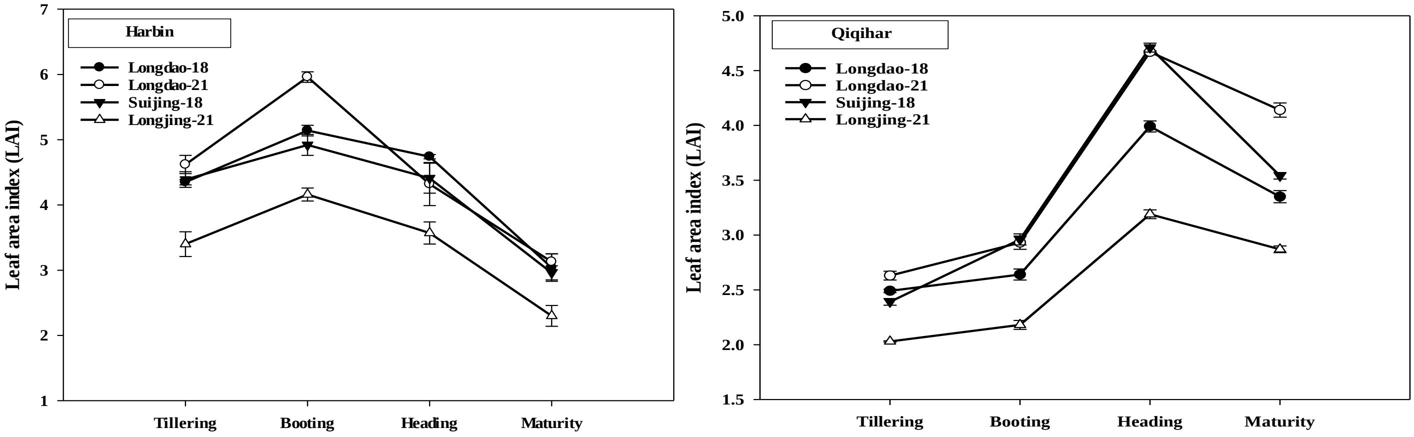

Figure 2A. Impacts of varying environmental conditions on leaf area index of four different cultivars in 2017 at Harbin and Qiqihar.

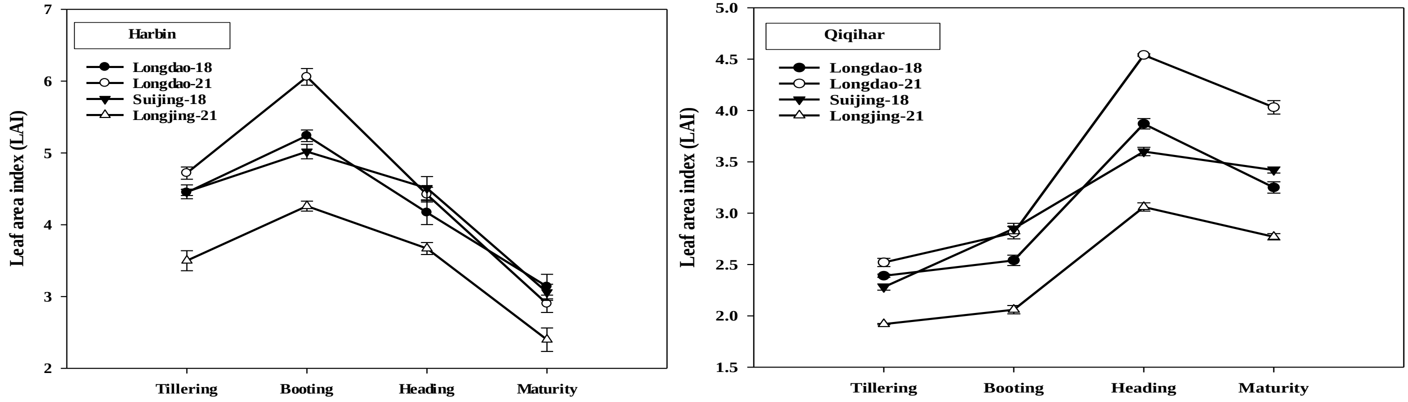

Figure 2B. Impacts of varying environmental conditions on leaf area index of four different cultivars in 2018 at Harbin and Qiqihar.

CGR is defined as the per unit area dry matter accumulation. CGR showed that very similar trend i.e., firstly increased then after grain filling stage as the crop moved towards maturity stage, it started to decrease. Maximum CGR at Harbin was recorded in cultivar Longjing-21 with value of 21.02 g m^{-2} day^{-1} at heading stage during 2018, and then it started to decrease, but the decreasing trend was bit rapid as compared to other cultivars as on maturity, the CGR value was less than 10 g m^{-2} day^{-1} whereas for other cultivars it was higher than 10 g m^{-2} day^{-1} at maturity as shown in figure 3B. At Qiqihar, maximum CGR was recorded in Suijing-18 as the growth during whole season was higher in this cultivar with highest value of 24.23 g m^{-2} day^{-1} during 2018 rice growth season. But at maturity the CGR values for this cultivar was less as at maturity, Longdao-21 had higher values figure 3B. The decreasing trend for Suijing-18 was rapid compared to other cultivars.

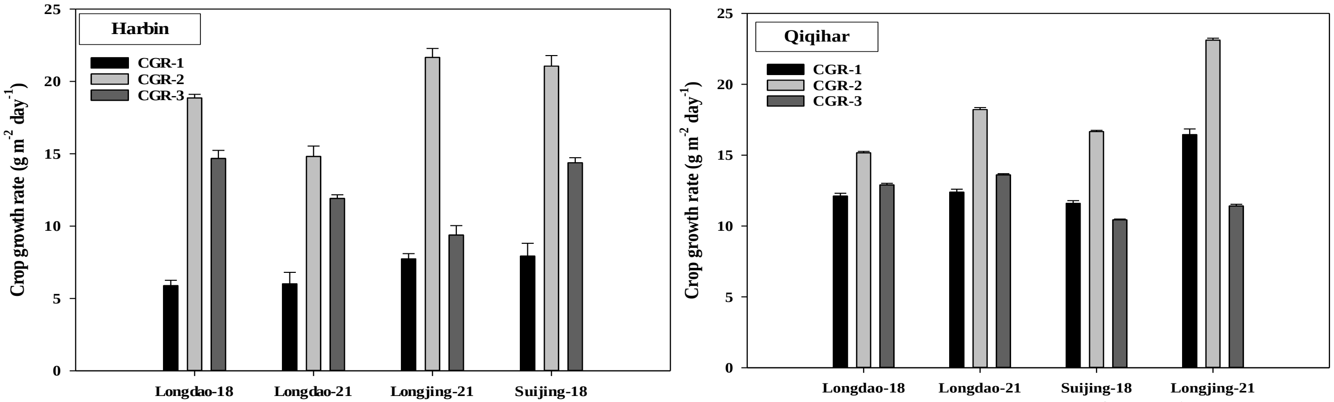

Figure 3A. Impacts of varying environmental conditions on crop growth rate (g m^{-2} day^{-1}) of four different rice cultivars in 2017 at Harbin and Qiqihar.

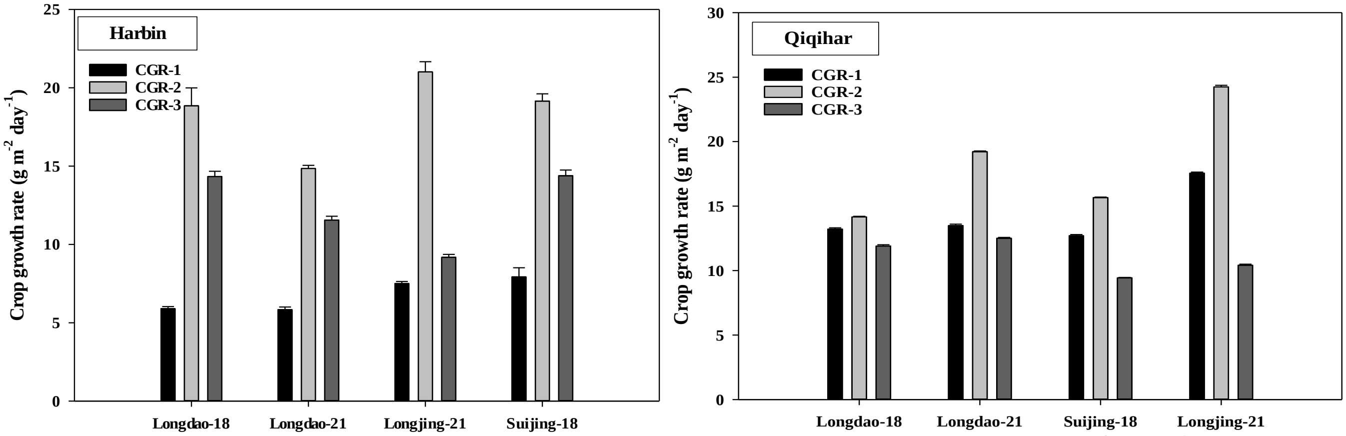

Fig. 3B. Impacts of different environmental conditions on crop growth rate (g m^{-2} day^{-1}) of four different rice cultivars in 2018 at Harbin and Qiqihar.

Grain-filling data

Grain weight accumulation for Harbin and Qiqihar for both growing periods is presented in figures 4A and 4B, respectively, whereas grain filling rates for Harbin and Qiqihar are presented in figures 5A and 5B, respectively. Grain weight accumulation for superior grains showed a typical S shaped trend line with high grain-filling rates whereas the dry weight of inferior grains though increased throughout the grain-filling period but with extremely low-filling rates. The grain filling period was consisted of 44 days for Harbin but for Qiqihar because of environment conditions prevailed during grain-filling period, it was bit shorter. Dry weight accumulation for superior as well as for inferior grains were highest in Longdao-21 followed by Longjing-21 and Suijing-18 during both seasons 2017 and 2018. Longdao-18 showed less values for dry weight accumulation as shown in figures 4A and 4B. The dry weight accumulation for inferior grains increased at extremely high rates and at a point it almost reached the dry weights of superior grains at the end of grain filling period at both sites.

Compared the grain weight accumulation of Harbin with Qiqihar in 2018, the cultivars showed low dry weight accumulation as highest values seen for superior grains were around 14 mg grain^{-1}. The grain weight accumulation for inferior grains was low at Qiqihar which might happened because of variation in prevailed temperatures during the grain-filling period at Harbin and Qiqihar that's why the values for dry weight accumulation at Harbin was extremely high than in Qiqihar during 2017 and 2018. The trend was same in 2017 and 2018 but the mean values for grain weight accumulation for all cultivars was less in 2017 than in 2018. The environment conditions prevailed during the grain filling period at Harbin and Qiqihar are given in Table 2, for 2017 and 2018s.

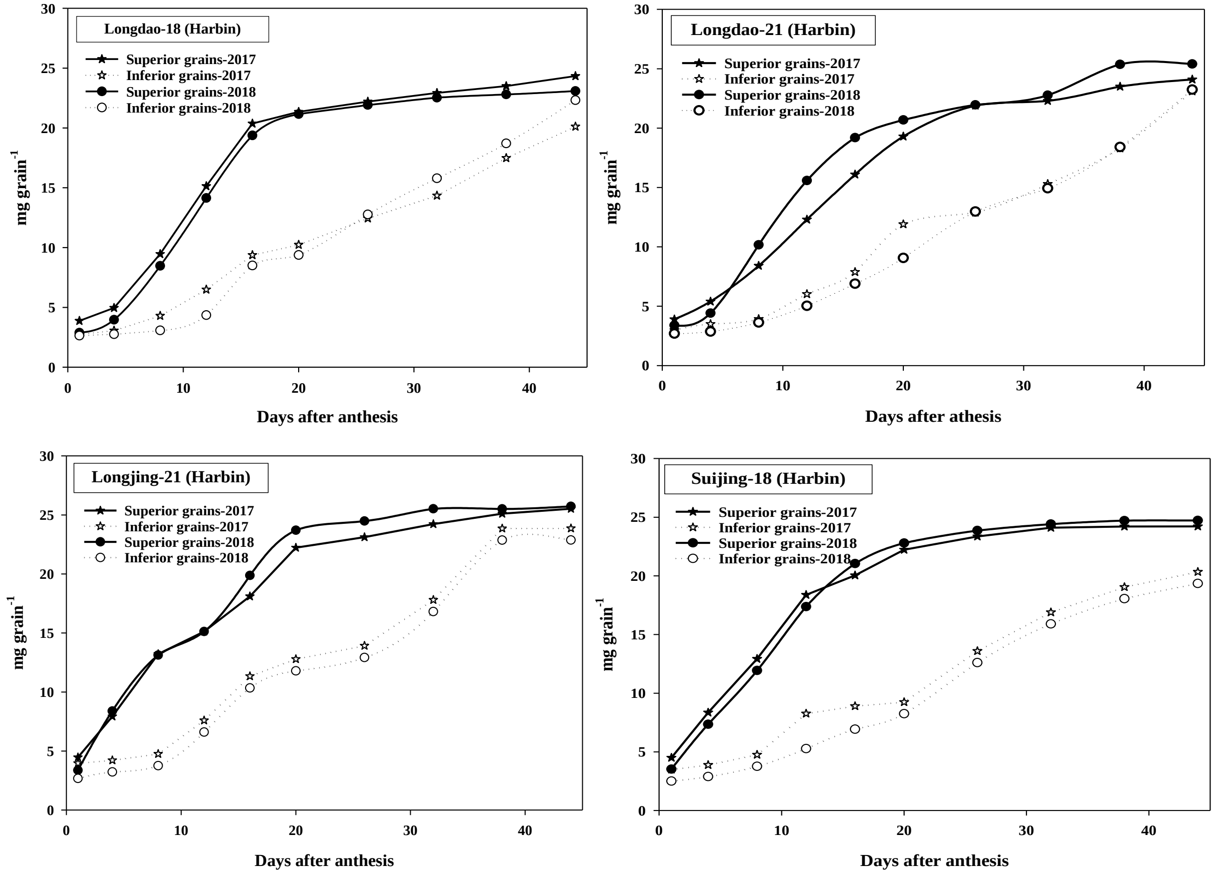

Figure 4A. Impacts of varying environmental conditions on grain weight accumulation (mg grain^{-1}) of superior and inferior grains of four different rice cultivars in 2017 and 2018 at Harbin.

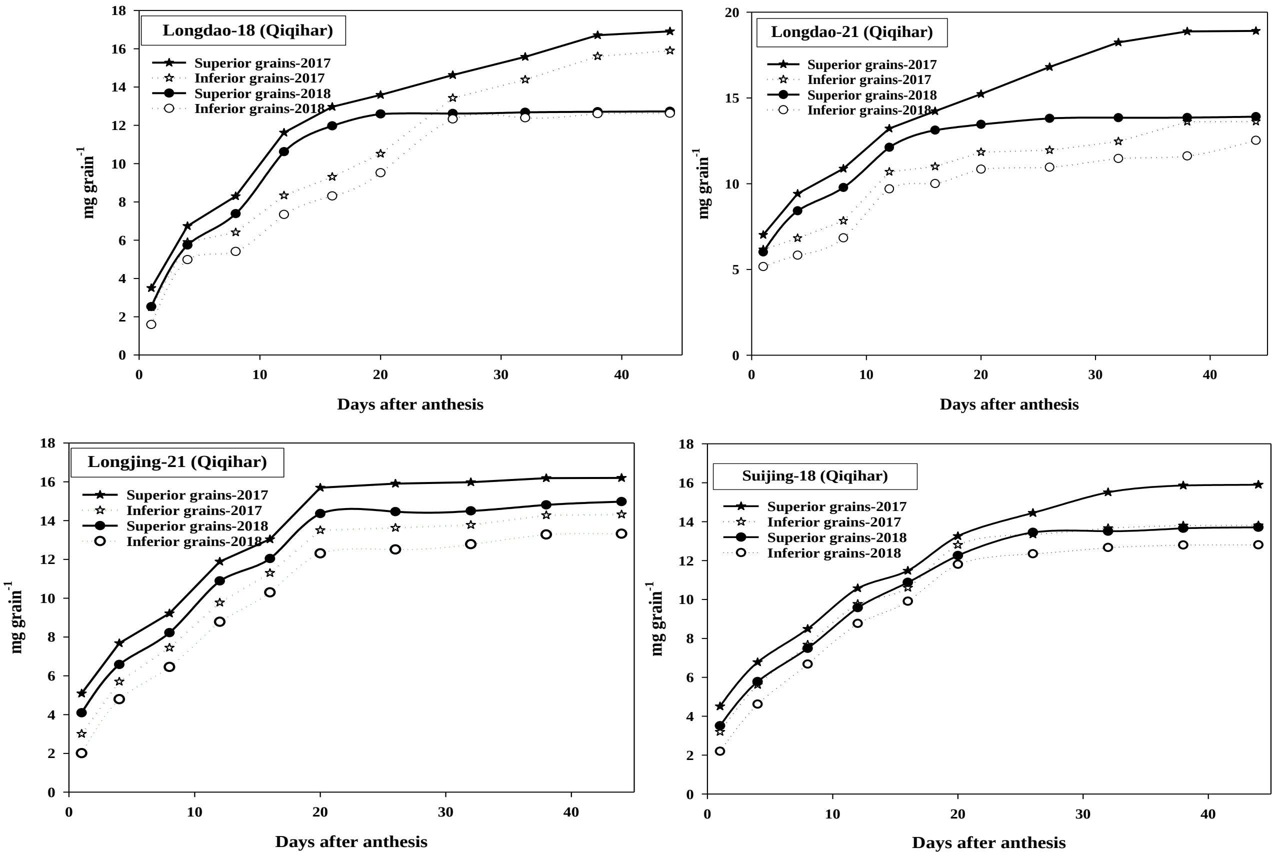

Figure 4B. Impacts of different environmental conditions on grain weight accumulation (mg $grain^{-1}$) of superior and inferior grains of four different rice cultivars in 2017 and 2018 at Qiqihar.

Table 2. Mean environmental conditions during the grain-filling stage at Harbin & Qiqihar during rice growth season of 2017 and 2018 (T_{avg}: average temperature; T_{max}: maximum temperature; T_{min}: minimum temperature; Rad: radiation accumulation; RH: relative humidity)

Cultivars	Region	Year	T_{avg} (°C)	T_{max} (°C)	T_{min} (°C)	Sunshine (h)	Rad. (MJ/m²)	RH (%)	Soil temp. (5cm) (°C)	Soil temp. (10cm) (°C)
Suijing-18	Harbin	2017	20.26	26.01	15.00	6.24	17.64	82.81	21.73	20.32
		2018	19.21	25.34	14.32	6.54	17.93	80.13	22.24	20.97
	Qiqihar	2017	18.44	24.38	12.96	7.30	16.72	80.99	19.77	18.23
		2018	19.67	25.14	13.45	7.41	16.98	78.16	21.05	20.53
Longjing-21	Harbin	2017	20.41	26.10	15.19	6.25	17.71	82.73	21.87	20.45
		2018	21.77	27.18	16.23	6.11	17.93	80.43	22.78	21.04
	Qiqihar	2017	18.62	24.44	13.26	7.16	16.66	81.44	19.91	18.37
		2018	18.93	25.67	14.54	6.98	16.34	79.12	20.45	19.13
Londao-21	Harbin	2017	19.97	25.68	14.80	5.75	16.81	83.36	21.24	19.84
		2018	20.90	26.81	15.61	6.61	16.09	81.90	21.78	20.12
	Qiqihar	2017	16.91	22.95	11.15	7.74	16.81	77.38	18.66	17.11
		2018	17.54	23.76	13.01	7.11	17.11	79.14	20.07	18.96
Longdao-18	Harbin	2017	20.15	25.92	14.99	5.88	17.09	83.32	21.48	20.06
		2018	21.43	26.12	16.73	6.13	17.56	81.45	22.11	19.76
	Qiqihar	2017	17.71	23.69	12.05	7.31	16.58	79.77	19.27	17.72
		2018	18.32	24.53	14.08	7.79	17.18	80.67	21.03	19.07

The values of dry weight accumulation for Longjing-21 and Suijing-18 didn’t show the trend line of typical S-shaped, as the values were less, and rate of grain filling was also low during both growing season 2017 and 2018. Low filling rate of inferior grains could not be attributed to temperature differences between superior and inferior grains, as the T_{max} and T_{min} during both periods of 2017 and 2018 were relatively constant, more specifically in 2018. Low filling rate finally led to a slow accumulation of grain weight and thus to incomplete filling of the inferior grains, resulting in a continuous increase of grain weight until harvest (Qiqihar). So, to increase the yield, there is a need to increase the grain filling rate of inferior grains along with superior grains through agronomic management practices. The grain-filling rates for both superior and inferior grains at Harbin for all cultivars were high up till harvest and showed perfect kind of loop shaped trend lines for all cultivars during both seasons 2017 and 2018 (figures 5A and 5B). But considering the mean values, if we compare 2017 with 2018, mean values were less in 2018 as compared with 2017 among all cultivars.

The interaction among cultivars for superior and inferior grains was highly significant in 2018, specifically and the grain-filling rate for superior grains was high around 2.5 times the filling rate for inferior grains. The trend line for Qiqihar didn’t show the loop shape comparison between superior and inferior grains as it was at Harbin. After 20 days of anthesis, the filling-rate became almost same for inferior grains as for superior grains (figures 5A, and 5B,). So, environmental conditions varied during the grain-filling period during both seasons 2017 and 2018, in the same way, the grain-filling rate and grain weight accumulation varied accordingly among cultivars at both sites.

Temperature is the one of the main components which affects the grain-filling, so difference in temperature might be possible to cause the variation in grain filling rate and weight accumulation. Dry weight accumulation and grain-filling rate for superior and inferior grains at Harbin showed significant varying trend lines during both growing seasons of 2017 and 2018 but at Qiqihar, the filling rate was almost same for both superior and inferior grains almost after 20 days of anthesis. The reason behind high dry weight accumulation at Harbin than Qiqihar among cultivars might be due to temperature variations, as the average temperature values during grain-filling was high at Harbin than Qiqihar. The average growing temperature for paddy rice during grain-filling period is 20-27 °C, so the average temperature during early weeks of grain-filling at Harbin was feasible than Qiqihar. When the cultivars were transplanted in Harbin and Qiqihar, the time difference between the superior and inferior grain of rice reaching the peak point of the grain filling curve showed obvious difference, indicating that the difference of climatic conditions between the two places had different degrees of influence on each cultivar.

Among cultivars, the time difference in grain-filling between Longdao-18 and Longjing-21 for inferior grains was 7-days and 4-days respectively, and Harbin was later than Qiqihar during 2018. The time difference in grain-filling of inferior grains in Longdao-18 was 5-days at two places, and Harbin was earlier than Qiqihar in 2018 among all cultivars. Moreover, the trend regarding time difference was almost similar for both superior and inferior grain filling rate in 2017. It has been indicated that the different climatic factors at two different sites had different impacts on the two early-maturing cultivars of the second accumulative temperate zone and first accumulative temperate zone, and had a great influence on the dry weight of the Suijing-18 and Longjing-21, whereas the dry weight accumulation as well as grain-filling rates were found less affected for Longdao-21 and Longdao-18 in 2017 as well as in 2018. The grain-filling period was divided into three stages to have consideration at which stage of grain filling was more and it was found during start, middle and late stages of grain filling period, at Harbin contribution rates were 39.44 %, 61.55 %, and 29.81 %, respectively, in growing season 2018. Whereas in 2017 it was almost same with bit variation in values as 38.11 %, 59.23 %, and 31.62 %, respectively. Therefore, the grain-filling curves for superior and inferior grains of different cultivars under different climatic conditions were mainly formed in the middle weeks of grain-filling period, which accounted for about 60% of the whole grain-filling during both season 2017 and 2018.

The present study confirmed that Richard's equation is a commonly used growth function with which general rate parameters were deduced in a simple manner. It can be seen from the values given in Table 3, that there was a significant difference between the maximum and the average grain filling rate of each cultivar between the two sites as well as between the superior and inferior grains during 2017 and 2018. The average grain filling rate values were higher for Longjing-21 and Longdao-21 followed by Longdao-18, but this trend was different at Qiqihar as the average grain filling rate was higher in Suijing-18 followed by Longjing-21 and Longdao-21. Similar results were observed regarding maximum grain filling rate at both sites for superior and inferior grains (table 3). The interaction and comparison were highly significant between the values in 2017 and 2018, as shown in table 3. The average and maximum grain filling rate of the inferior grains were higher in Harbin than those of Qiqihar during both seasons in 2017 and 2018. Among the cultivars in the two sites, the average and maximum grain filling rate of the superior grains were much higher than the inferior grain at Harbin.

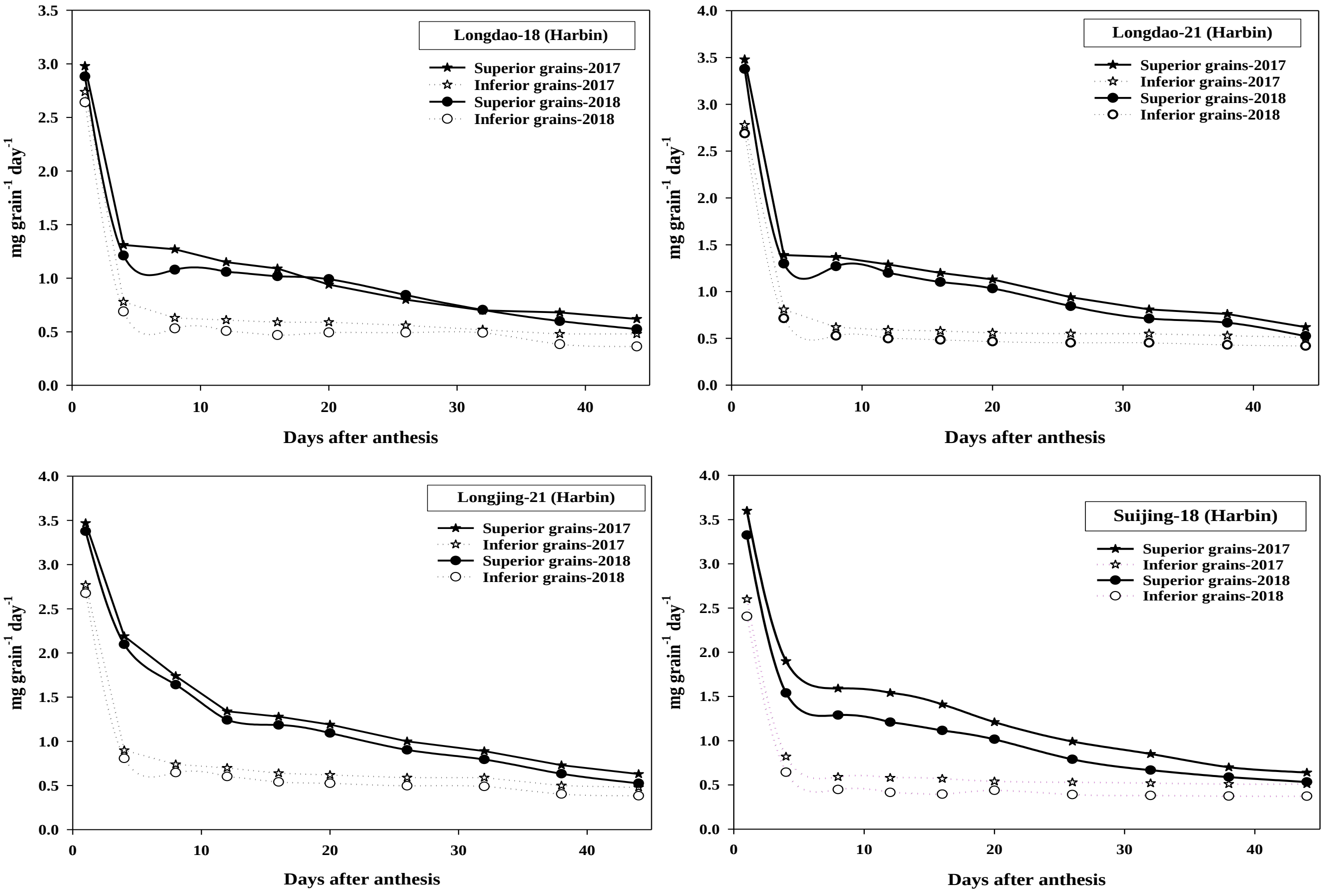

Figure 5A. Impacts of varying environmental conditions on grain-filling rate (mg grain^{-1} day^{-1}) of superior and inferior grains of four different rice cultivars in 2017 and 2018 at Harbin.

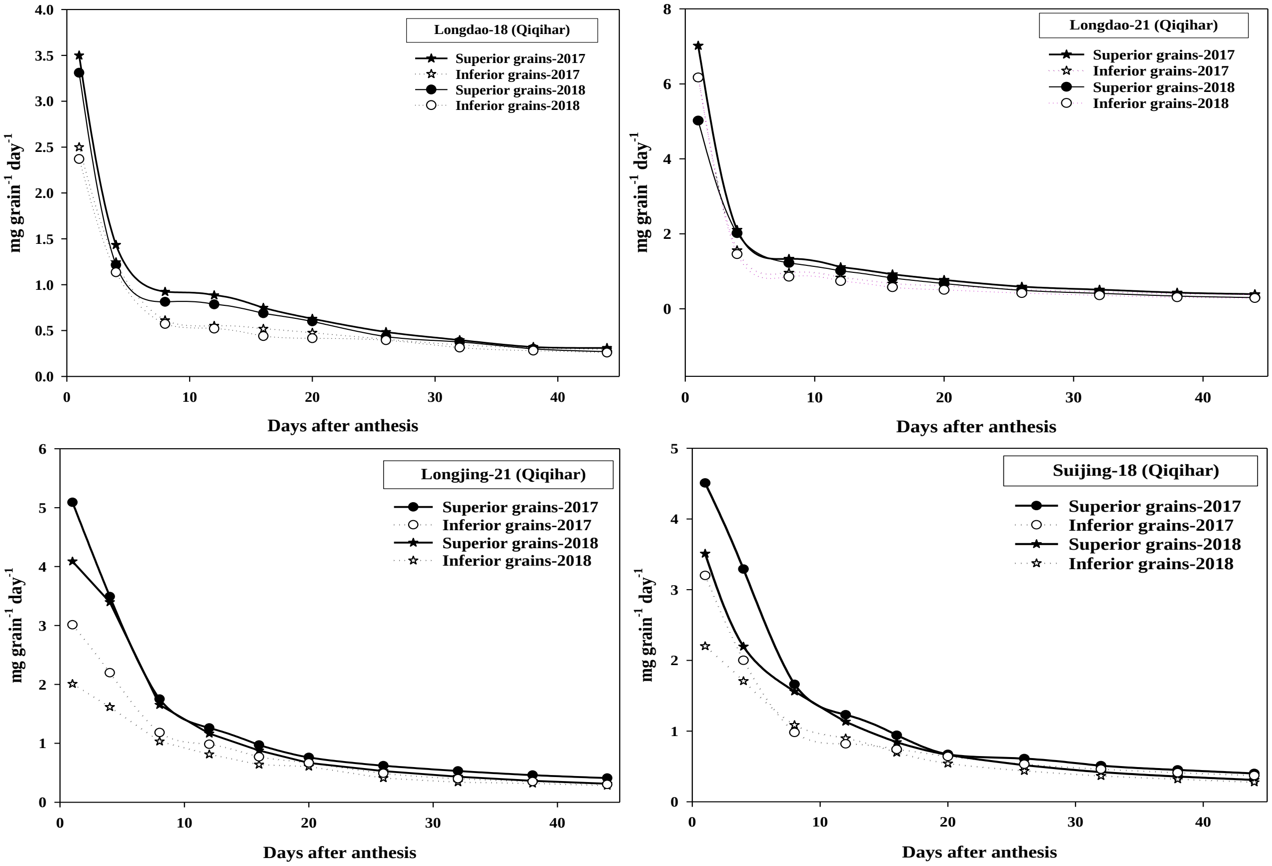

Fig. 5B. Impacts of varying environmental conditions on grain-filling rate (mg grain^{-1} day^{-1}) of superior and inferior grains of four different rice cultivars in 2017 and 2018 at Qiqihar.

Quality assessment

The findings of this study indicate that the chalkiness and brown rice percentages were higher in Qiqihar than Harbin during both growing seasons 2017 and 2018 as shown in Table 4. The starch and carbohydrate contents were higher among all cultivars at Harbin than Qiqihar. Fine rice percentage, amylose and protein contents were high among all cultivars at Harbin. So, overall, the quality of rice was better at Harbin if compared with Qiqihar as shown in table 4. Length and width of rice grains were also higher at Harbin than Qiqihar.

Table 3. Impacts of varying environmental conditions on final grain weight (GW), time to reach maximum grain-filling rate (T_{Gmax}), maximum grain-filling rate (GFR_{max}), and average grain-filling rate (GFR_{avg}) during 2017 and 2018.

Cultivar	Grain Type	Region	GFR_{max} (mg grain^{-1}day^{-1})		T_{Gmax} (days)		Gw (mg)		GFR_{avg} (mg grain^{-1} day^{1})		GFD (days)		R^2	
			2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Suijing-18	Superior	Harbin	1.64	2.88	13.09	12.07	10.32	22.80	1.10	1.60	31.78	30.42	0.9990	0.999
		Qiqihar	2.61	1.62	12.63	17.58	08.45	18.70	1.95	0.90	21.82	20.18	0.9981	0.989
	Inferior	Harbin	1.08	3.37	20.84	10.73	09.24	25.38	0.73	2.20	47.13	46.31	0.9998	0.995
		Qiqihar	0.77	1.68	14.13	16.51	05.75	18.41	0.52	0.91	44.41	43.14	0.9835	0.993
Longjing-21	Superior	Harbin	1.59	3.31	14.49	14.49	11.15	25.43	1.07	2.35	33.93	34.39	0.9991	0.989
		Qiqihar	3.21	1.67	12.57	20.16	08.36	22.86	2.75	0.88	18.14	17.41	0.9948	0.998
	Inferior	Harbin	1.32	3.52	20.16	13.09	10.18	24.21	0.89	2.35	41.11	40.17	0.9994	0.994
		Qiqihar	0.26	1.50	16.54	20.84	00.74	19.34	0.58	0.85	54.03	55.23	0.9875	0.995
Longdao-21	Superior	Harbin	1.72	1.43	10.73	11.90	10.85	12.59	1.16	1.07	28.88	30.18	0.9989	0.987
		Qiqihar	1.46	1.24	09.24	22.05	08.33	09.52	1.00	0.63	32.21	31.11	0.9972	0.985
	Inferior	Harbin	0.86	2.10	16.51	09.24	07.34	13.86	0.59	1.81	52.82	51.42	0.9951	0.981
		Qiqihar	0.88	1.45	17.80	17.80	07.51	10.85	0.60	0.92	50.37	49.17	0.9913	0.989
Longdao-18	Superior	Harbin	1.62	3.10	12.07	12.57	10.42	13.48	1.09	1.99	29.68	30.18	0.9993	0.993
		Qiqihar	1.04	1.90	11.90	16.54	07.78	11.35	0.71	1.09	44.40	43.10	0.9934	0.977
	Inferior	Harbin	0.84	3.39	17.59	12.63	06.95	13.76	0.57	2.05	52.56	51.86	0.9973	0.997
		Qiqihar	0.47	2.19	22.05	14.13	05.37	12.75	0.32	1.01	71.47	70.77	0.9974	0.987

Chalkiness is the negative factor for rice quality that’s why quality of rice was bit better at Harbin than Qiqihar. As given in Table 4, the chalkiness percentage for rice among all cultivars were higher at Qiqihar in 2017 which was higher as compared to the recordings of 2018. So, chalkiness percentage was higher during both growing seasons in 2017 and 2018.

Table 4. Impacts of varying environmental conditions on quality of four different rice cultivars during 2017 and 2018 at Harbin and Qiqihar (BR: brown rice; FR: fine rice; L–W: length-width, GL: grain length; GW: grain width).

Region	Cultivar	Year	Protein (%) mv ± sd* a**	Amylose (%) mv ± sd	BR (%) mv ± sd	FR (%) mv ± sd	L-W ratio mv ± sd	GL (mm) mv ± sd	GW (mm) mv ± sd	Chalkiness (%) mv ± sd
Harbin	Longdao-18	2017	7.1 ± 0.1 c	17.8 ± 0.2 a	75.5 ± 3.1	68.6 ± 2.9	2.1 ± 0.09 a	5.3 ± 0.17 ab	2.6 ± 0.01 b	1.0 ± 0.3 b
		2018	7.8 ± 0.1 b	18.9 ± 0.1 a	77.4 ± 2.2	67.6 ± 2.4	2.0 ± 0.07 a	5.2 ± 0.15 a	2.5 ± 0.01 b	0.9 ± 0.4 b
	Longdao-21	2017	7.1 ± 0.1 c	17.5 ± 0.2 ab	74.2 ± 5.2	66.7 ± 5.1	2.2 ± 0.04 a	5.4 ± 0.53 a	2.5 ± 0.03 c	0.7 ± 0.1 b
		2018	7.8 ± 0.2 b	18.4 ± 0.3 ab	76.1 ± 5.2	66.0 ± 4.8	2.1 ± 0.03 a	5.0 ± 0.03 b	2.4 ± 0.02 c	0.6 ± 0.2 b
	Longjing-21	2017	8.9 ± 0.6 a	15.9 ± 0.6 c	76.2 ± 4.3	69.3 ± 3.2	1.8 ± 0.02 c	4.6 ± 0.13 b	2.7 ± 0.02 a	2.1 ± 0.3 a
		2018	9.0 ± 0.4 a	16.8 ± 0.7 c	78.3 ± 4.0	68.6 ± 3.5	1.7 ± 0.03 c	4.5 ± 0.08 c	2.6 ± 0.01 a	2.0 ± 0.4 a
	Suijing-21	2017	8.1 ± 0.2 b	16.9 ± 0.2 b	75.5 ± 3.4	68.9 ± 3.6	1.9 ± 0.03 b	5.1 ± 0.08 ab	2.7 ± 0.02 a	1.0 ± 0.5 b
		2018	8.8 ± 0.1 b	17.7 ± 0.2 b	77.7 ± 3.4	68.1 ± 2.8	1.9 ± 0.03 b	5.0 ± 0.09 b	2.6 ± 0.03 a	1.0 ± 0.6 b
Qiqihar	Longdao-18	2017	6.6 ± 0.2 b	16.8 ± 0.2 a	78.4 ± 2.8	64.6 ± 2.3	1.9 ± 0.02 a	4.8 ± 0.25 a	2.5 ± 0.01 a	1.1 ± 0.1 b
		2018	6.7 ± 0.3 b	17.9 ± 0.2a	79.6 ± 2.8	65.7 ± 2.3	1.9 ± 0.02 a	4.7 ± 0.25 a	2.4 ± 0.02 a	1.0 ± 0.2 b
	Longdao-21	2017	6.2 ± 0.1 b	16.4 ± 0.4 ab	77.2 ± 6.6	62.1 ± 3.7	2.0 ± 0.04 a	4.3 ± 0.11 b	2.3 ± 0.01 b	0.8 ± 0.2 b
		2018	6.5 ± 0.3 b	17.3 ± 0.3 ab	78.7 ± 6.6	63.2 ± 3.7	1.9 ± 0.04 a	4.2 ± 0.11 b	2.2 ± 0.01 b	0.8 ± 0.3 b
	Longjing-21	2017	7.3 ± 0.1 a	15.0 ± 0.8 c	78.9 ± 4.4	65.3 ± 3.6	1.6 ± 0.02 b	4.2 ± 0.06 b	2.6 ± 0.08 a	2.6 ± 0.3 a
		2018	7.6 ± 0.5 a	15.9 ± 0.8 c	80.1 ± 4.4	66.4 ± 3.6	1.7 ± 0.02 b	4.1 ± 0.06 b	2.5 ± 0.07 a	2.4 ± 0.4 a
	Suijing-21	2017	7.9 ± 0.2 b	14.9 ± 0.3 b	77.8 ± 4.2	64.1 ± 2.9	1.8 ± 0.03 b	4.3 ± 0.09 b	2.4 ± 0.09 a	1.4 ± 0.3 b
		2018	7.2 ± 0.6 b	16.9 ± 0.2 b	78.9 ± 4.2	65.1 ± 2.8	1.8 ± 0.03 b	4.2 ± 0.09 b	2.4 ± 0.06 a	1.3 ± 0.4 b

(*mean values ± standard deviation; **DMRT to differentiate the groups of means)

Our findings regarding Japonica rice improvement were based improving the agronomic and yield characteristics. Most of the japonica varieties in the northern and northeastern regions of China mature in 140-150 days. Identifying the short growth duration among rice cultivars was one of most important objectives because early maturing varieties can survive from cold or temperature stress at later growth stages to optimize the yield. Rice plants among cereal crops require large amount of water for optimum growth and development for both reproductive as well as vegetative phase. Based on the results, rice production especially in northeast of China, is highly dependent on precipitation though the artificial irrigation is available. Along with precipitation, temperature also plays a leading role in plant growth and development. So, our results were completely based on all the climate factors which have any kind of direct or indirect influence on rice growth, development and yield.

Based on the results, if we compare the plant height component of both sites, then it was observed that rice plants were taller at Qiqihar than Harbin. However, plant height is one of the main components which contributes in overall biological yield. The temperature requirement for enhanced aerial growth of rice is 18-33°C after transplanting. Therefore, plant height usually increases until the heading stage approaches but on heading stage, plant ceases its aerial growth. Plants on both sites increased their aerial growth up till heading stage, both sites showed higher plant height values but if we compare the interaction, it was showing the values were bit high at Qiqihar though interaction was non-significant. These results are in line with previous studies reported by (Oh-e et al., 2007) who concluded that the increase in plant height was steeper under high temperature than under ambient temperature condition. During early months the plant height increased slowly but in later months plant height increased more steeply when the temperature was high. Rice grain yield in any given environment is usually determined by yield components (panicle length, tillers fertility and grains per panicle) which were developed at different phenophases. Based on the results, the cultivars grown in a specific environment, their yields are influenced by the respective prevailed environmental conditions that plant experiences during different growth stages. Therefore, rice production systems along an altitude gradient, such as in Northeast China specifically Heilongjiang province, have been traditionally stratified into three types of latitudes i.e., low, mid and high-altitude environments. According to the findings, cultivars that have been specifically selected according to region’s environment were bred for those environments and adapted to those areas based on local cropping calendar aiming higher yields. Because of climate change, there is a rendered relationship between cultivars' adaptation and the respective growing environment conditions, since environmental conditions would keep on varying significantly every year e.g., temperature, amount and frequency of precipitation, intensity and the accumulation of solar radiation etc. may become more intense or mild (WASSMANN et al., 2009; MEEHL et al., 2007). So, variation in environmental conditions may bring new combinations e.g., higher or lower temperature may cause new combination with pest existence along the altitudes (WEERAKOON et al., 2008), higher temperature at anthesis may cause combination of fertility of spikelets or appearance of new pests across the gradient with available water etc. (KOCMÁNKOVÁ et al., 2010; RANG et al., 2011). If it happens, then possible adjust-control measures are necessarily required to minimize the yield loss by adjustments in management practices e.g., shifts in planting dates for nursery, changes in dates for transplantation or changes in inputs amendments method and type etc. which would lead to significant changes in rice yields and crop duration specifically across altitude gradient (SHRESTHA et al., 2011).

One of the major reasons for rice yield variation is growing the cultivars which are not being adapted to a specific environment different from the ones it was adapted for, that would increase the whole crop failure or may be risk in yield loss. In previous studies, (PENG et al., 2006; ACUÑA et al., 2008), it was suggested that yield stability in this case among different environments could be accompanied by changes in management practices through possible adjust-control measures or yield target can be achieved by having bumper crop yields under favorably selected high-yielding environments. In the present study, we evaluated that the two different environments were defined on location basis in Heilongjiang province of northeast China, 4 cultivars were selected same for both environments, the sowing of nursery and transplantation dates for all cultivars within a specific environment was same but between sites they were different. Our findings indicated that the two environments differed in their average values of environment components that prevailed during the growing season. Our results are consistent with that of (LU et al., 2008) who reported that the variation in yield components and yields among cultivars within a site and between two sites can be explained by possibility of non-adaptability of a specific cultivar to a specific environment or may be temperature or precipitation variation on a specific growth stage. Yield variation among cultivars and between sites can also be explained that temperature stress might coincided with a specific growth stage brought shifts in the phenological phases which was responsible for the formation of different yield components at different times under favorably selected environmental conditions (BAJRACHARYA et al., 2010). Productive tillers, number of grains per panicle, panicle length and 1000-grain weight were the yield components most influential on yield at two sites. Both cold and heat temperature stresses can cause cold and spikelet sterility as well as it can disturb the pathway for source-sink that have been well briefed for rice (DINGKUHN et al., 1995; SHRESTHA et al., 2011).

We suggested that temperature cannot cause the variation in grain yield among all cultivars between two sites but rather variation happened due to the combined effects of other environmental factors the cultivars experienced during the different growth and developmental stages during the different yield components were formed. In current study, it has been analyzed that how different environments influenced the individual yield component at respective growth stage i.e., panicle length enhancement, 1000-grain weight, number of productive tillers. These results are in accordance with (AO et al., 2010) who observed that the effects of enhancing number of productive tillers and reducing the unfertile tillers per hill which cannot influence the yield positively. More tiller number is the most important yield component to enhance the net grain yield across different environments and different planting dates according to the prevailing environmental conditions (MORADPOUR et al., 2013). Similar results were observed that vegetative growth and yield are also mainly influenced by availability of water during the growth season. So, final grain yield might get influenced greatly across different environments depending on the availability of water regimes. In the present study, response of all cultivars was stronger in terms of grain yield with an increase in productive tillers when the prevailing environmental conditions became more favorable, however, important point was that yield components were high in cultivars those were generally adaptable to an environment. So, tillers per hill had little influence on yield but productive tillers had great influence. Fertility of tillers was found to be the environment dependent trait (AKINWALE et al., 2011; ZHU et al., 2011; LIU et al., 2013). However, this study revealed that yield stability varied across both environments. Grain per panicle can regarded as the ultimate sink potential, but grains per panicle has been found it was less environment dependent and showed more dependency on genetic control (KOVI et al., 2011; AKINWALE et al., 2011) but indirectly can be influenced by temperature effects on panicle length (KOVI et al., 2011). Number of total filled spikelets which was clearly temperature influenced trait and influence can only be reduced by avoiding detrimental environmental conditions (data not shown). Therefore, total grain yield of rice directly depends on the cumulative solar radiation and cumulative mean temperature that prevailed during grain-filling period.

Our results depict that prevailed environmental conditions regarding these two components were favorable, thereby the grain-filling rate and duration enhanced. It has been revealed that duration of grain-filling period directly depends on optimal solar radiation as well as optimal temperature as enhanced grain-filling duration determines the final rice grain yield (YANG et al., 2008). One of the major approaches to measure the crop photosynthesis is leaf area index (LAI). At different growth stages, it was purposed to concise the varying relationship between crop growth and LAI development among different rice cultivars grown under different environments. These results are in line with the previous study reported by (TARDIEU, 2013) who concluded that temperature dependent processes in LAI development e.g., appearance as well as the elongation of individual leaves responded positively to high temperature at different growth stages, However, if higher temperature continues up till a sensitive growth stage arrives e.g., flowering, then biomass production becomes reduced because of combined effects of other environmental factors such as radiation interception by the crop and its absorption efficiency. LAI values were higher at Harbin than Qiqihar and the decreasing trend after heading at Qiqihar was also steeper than Harbin. As the prevailing environmental conditions would become favorable according to the requirement of a specific growth stage, the dry matter production will be enhanced, and leaf area will continue to increase accordingly, ultimately the yield will be higher. Taking an example of temperature stress, either cold or heat stress affect the vegetative as well as reproductive stage and cause shift of specific growth stage. In this study, at Qiqihar because of wet season the yield was higher, but temperature stress might cause the lowering of LAI and CGR values at Qiqihar. The interaction between temperature and rice cultivars between two sites was highly significant. It has been found temperature variation caused decrease in LAI and total dry matter accumulation (AGHAEE et al., 2002; NAGAI & MAKINO, 2009). These results are in agreement with that (PITMAN et al., 2004) who reported that crop matures early or late, it strongly depends on temperature variation, changes in altitudes crop duration is strongly influenced by temperature and altitudes, and seasonal mean temperature that vary due to the altitudinal temperature gradient of 7℃per km at 60% air humidity.

Temperature variation and more specifically higher temperature influence the quality of rice if prevailed during grain-filling phase (AMBARDEKAR et al., 2011; LISLE et al., 2000; COOPER et al., 2008). If temperature becomes high during early grain filling period, then it will cause enhanced endosperm cell division, fewer grains will start to build, presence of lesser number of building blocks within walled cells, thereby increased chalkiness percentage on grain (ZHANG et al., 2008). If temperature variation continues to prevail even during night, then grain will be occupying higher degree of chalkiness (COUNCE et al., 2005). According to our findings, temperature is one of most important components which affects the grain-filling process and ultimately the quality of rice. In the present study, we evaluated that in early weeks of grain-filling the temperature was more favorable at Harbin than Qiqihar but vice versa during last weeks of grain-filling period. But, overall, the cumulative mean temperature at Harbin was more favorable at Harbin than Qiqihar. However, in our study Qiqihar was found cooler than Harbin that's why all cultivars showed more chalkiness degree on grains than found at Harbin. Unlike the temperature, solar radiation and mean radiation accumulation also affected the quality of rice grains as they are negatively associated with chalkiness and relative humidity percentage during grain-filling found positively associated with chalkiness. Overall, the quality of rice was better at Harbin among all cultivars because of better prevailed environmental components than in Qiqihar as negative quality trait was higher at Qiqihar and positive traits were higher at Harbin.

With changing global climate, extreme cold or extreme hot conditions will be more frequent in the future depending on the regions, which will make rice subject to adverse abiotic stresses. So, the need to improve the tolerance against climatic variability in rice at reproductive stage during anthesis is the most beneficial for adaptation to highly dynamic climatic conditions (MATSUI et al., 2001). Moreover, enhancing the absolute stress tolerance in rice could make it possible to carry out the important physiological processes (pollen germination, pollination, anther dehiscence, and fertilization) for higher spikelet fertility under stress (JAGADISH et al., 2007). It has been found by (RANG et al., 2011) that anthesis under different environments might largely determine the fertility of spikelets. Temperature conditions at Harbin was more in the optimum range during the anthesis and preceding events at Harbin than Qiqihar, and less intensity and frequency of precipitation positively influenced the anthesis. In general, anther dehiscence can affect the number of pollen grains on the stigma (RANG et al., 2011). Similar results were reported by (RANG et al., 2011) who indicated that cold sensitiveness among cultivars might cause the infertility of the spikelets. However, the reason behind anther dehiscence between sites was that anthers still dehisced under stress due to spikelet flowering; swelling of pollen grain was poor, that might be the cause in losing their viability, resulting in unfertilized pollen as reported by (ZENG et al., 2017).

Strong variations were reported in this study regarding rice spikelet time of onset and end of anthesis between climatic environments, whereas the duration of anthesis varied comparatively little. Across two environments, atmospheric T_{min}, averaged over the 7d preceding any respective anthesis event was the one of the major reasons behind almost all variations similarly as reported by (KOBAYASI et al., 2015), whereas higher temperature caused spikelets to open earlier in the morning, but no significant effect of solar radiation was reported on anthesis duration. No environmental effects on anthesis time were reported within a site because of insufficient variability, but the effects were caused by other factors rather than environment e.g., management including irrigational management practices etc. It has been reported by (KOBAYASI et al., 2015) that decrease in day length by 1h (or application of a dark treatment before anthesis time) could delay (or advance) the onset of flowering. Jagadish et al. (2007) suggested that rice spikelet sterility is affected by thermal stresses mainly at two critical periods, one is microscopic stage during meiosis and second is about two weeks later during anthesis when pollination is about to start. Therefore, first critical phase is mostly affected by cold stress or chilling but rarely by heat.

Based on the above discussion, we assumed that there was great cultivar variation regarding growth duration and final grain yield between two sites. When the cultivar variation regarding all crop data analyzed by combining with the environmental factors that prevailed between two sites during growth periods, associations depicted that there would be requirement for adjusting the rice growing in these two sites. Despite the fact of knowing the variation in genetic control, analyses of grain-filling rate, grain weight accumulation, yield components, and final grain yield has shown most of the yield components responded strongly to varying environmental conditions and thus influenced final yield.

CONCLUSIONS

This study provided evidence of strong effects of different environments on growth, yield components, grain filling, and quality of rice and time of day of anthesis. From this study we got adaptive values regarding time of day of anthesis i.e., effects of air temperature specifically T_{min}. This research is of greater adaptive value, majorly for scenarios conducted for global warming, where heat induces spikelet sterility more expectedly to be leading constraint to grain yield. Higher temperature on earlier anthesis at the start of the day thereby increases the probability of escape from the even higher temperatures stresses later during the day. Earlier anthesis under humid conditions provides for potential escape from rising ambient temperatures during the day. Temperature is one of most important components which affects the grain-filling process and ultimately the quality of rice. So, due to favorable conditions, most of the grain-filling was seen during middle period at Harbin as filling period was divided into three phases i.e., early, middle and late, which accounted for almost 60% of the whole grain-filling process. At three phases of filling period, the contribution rates at Harbin were 39.44%, 61.55%, and 29.81% in 2018 and 38.11%, 59.23%, and 31. 62%, in 2017. At Qiqihar, most of the grain filling was seen at late phase of filling period because of suitable climatic conditions at later filling phase. This study confirmed that variation in grain yield is not only due to variation in temperature between two sites but variation happens due to the combined effects of other environmental factors that the cultivars experience during different growth and developmental stages. Most of the grain yield components and grain yield values were significantly higher at Qiqihar as compared to Harbin because of favorable environmental conditions at respective growth stages. Late maturing cultivars i.e., Longdao-18 and Longdao-21 showed higher values of grain yield at both sites Harbin and Qiqihar, (9500 kg ha^{-1} and 9166 kg ha^{-1}), and (13267 kg ha^{-1} and 13133 kg ha^{-1}), respectively. According to our findings, the quality of rice at Harbin was considerably better than Qiqihar because temperature at Qiqihar became higher during grain-filling period, which enhanced endosperm cell division, few grains were started to build, fewer number of building block within walled cells and ultimately enhanced chalky areas on grains. Another main finding, we reported in this study, that rice transplantation on early dates can favor the enhancement in grain yield and tallest plants will be produced. Hence earlier transplantation can prove to be promising to avoid the later cold stress and precipitation impacts on anthesis. Good quality rice can be achieved through possible shifts in transplanting dates, mainly bit early transplanting at Qiqihar to avoid quality degradation. Therefore, shifts in transplanting dates based on crop variety and local region, can be considered as an adaptation strategy to enhance rice quality. Early maturing and short duration holding cultivars are recommended for both regions specifically for Qiqihar to avoid the cold stress on later stages especially on ripening and maturity. Heat stress at ripening stage reduces the yield and quality of rice. Higher temperature wave at ripening stage in Harbin mainly decreased the quality and production of rice. There is a requirement and suggestion to extend this study for the assessment of the combined impacts of more than two environmental components to improve the adaptation strategies under continuously changing climate, for the sustainability and profitability of rice system in Northeast China. Evaluation of impacts other than average climate change like extreme events (floods, droughts etc.), pests, and diseases should be considered for future studies accompanying NEC.

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