Effects of High Temperature on Yield and Grain Quality of Rice in Taiwan

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Abstract: Since the introduction of japonica type rice in the 1920's, Taiwan has been the lowest latitude region where japonica type rice cultivars are dominated cultured. There are two rice crop seasons in Taiwan. Temperatures of the two cropping seasons of Taiwan are naturally higher than that of temperate countries. The temperature has been increasing during past 100 years at rate of 0.15℃/10 year and is projected to increase in the future at the rate of 0.1 – 0.3℃/10 year. During the recent 30 years temperature even increased with rate of 0.36℃/10 year. Data revealed that culture management might be already modified by farmers to adapt the climate change. Field experiments have been conducting to explore relationships among temperature, yield, and quality traits; and the results are discussed in the present report.
Key words: high temperature, heat, rice, yield, quality, Taiwan

1. Geographic position and current status of rice production in Taiwan

Taiwan locates at the subtropical region with the Tropic of Cancer across the southern area of the island. Based on a recent archeology study, rice cultivation and breeding activities have proceeded since more than 4000 years ago. At the present japonica, indica, and even javanica types of cultivars have been cultivated in Taiwan. Most of Taiwan rice varieties belonged to indica type before the 1920s. Japanese scientists successfully developed japonica type varieties (so called Pon-lai type rice) around the 1920s and japonica type varieties currently account for more than 90% of cultivars in Taiwan. Taiwan is one of the lowest latitude regions where japonica type varieties are dominantly cultivated [5].

Taiwan has two rice crops a year. Planting acreage of rice is about 136,000 ha for the 1st crop and 100,000 ha for the 2nd crop. The brown rice yield is about 5,400 kg/ha for the 1st crop and 4,300 kg/ha for the 2nd crop. High temperature during vegetative stage (July to August) is recognized as the main factor limiting the yield of the 2nd crop [6].

2. Current objectives of rice improvement of Taiwan

Until the 1980s, the 'yield' had been the most important goal of rice improvement. The objective has shifted to quality improvement after Taiwan had surplus rice production during the late 1970s. Currently the focus of field management system, storage and milling facilities, as well as market management strategy are all orientated toward the elevation of grain quality (both appearance and palatability) and the increase of market prices and competitiveness. In recent years 'safety' has been gaining heavy social awareness in aspects of both food and environmental sustainability. Cultivation systems including organics, traceability, HACCP, and eco-farming have been rapidly developed and incorporated into Taiwan rice industry [4].

In regarding breeding, most of Taiwan varieties are developed by pure line breeding system. The objective has been moved from high yielding to high grain quality since the 1980s. Evaluation of grain appearance and palatability are essential before a new variety can be released. Most of the modern cultivars are so called premium or quality rice varieties. Nevertheless, narrowing genetic background has become a significant challenge may be due to the simplified breeding objective. To improve the market uniqueness and competitiveness, varieties with special characters have become an attractive focus of breeding, including aroma, color, unique nutrient content, as well as the suitability for brewing.

3. Climate of rice culture

Taiwan has two rice crops a year. In general the first crop is transplanted in January, heading in May, and harvested in June; and the second crop is planted in July, heading in October and harvest in early November. There is about one month difference of the timing of transplanting, heading and harvest along the Taiwan island from south to north areas [6].

Trends in change of temperature are significantly different between two cropping seasons. Average daily temperature increases from 15℃ to 28℃ for the 1st crop; while decreases from near 30℃ to 18℃ for the 2nd crop. Temperature for tillering stage is lower in the 1st crop than that in the 2nd crop; while temperature for grain filling stage is higher in the 1st crop than that in the 2nd crop [4]. High temperature stress (>30℃) frequently occurs at grain filling stage in the 1st crop and at tillering stage in the 2nd crop season [3].

In comparison with temperate climate regions where only one crop (japonica type) is cultivated, such as Japan (Fig. 1), rice culture is 'always' under high temperature and low radiation (< 13 MJ/day during growing season) environments [4, 5]. This climate environment has been recognized as the main constrain for the improvement of yield and quality of culture japonica type rice in Taiwan.

4. Trends of climate change in Taiwan

Climate change does pose challenge on yield and quality of Taiwan rice production. It is found that the temperature has been increasing by the rate about 0.15℃/10 year, which is faster/higher than the global average rate of warming [2]. The warming status is even significant during the recent 30 years with rate of 0.36℃/10 year. Increase of night temperature is the main course for the warming trend. In addition the radiation has also decreased during past 100 years [3]. During both cropping season the frequency of maximum daily and night temperature has also increased during recent 10 years [2, 3].

With respect to the future, the temperature is estimated to increase by 0.1 – 0.3℃/10 years in Taiwan, which is faster than the trend of the globe [7]. The increasing temperature will be a significant challenge to the yield and quality of Taiwan rice as described below.

5. Effects of temperature on grain yield and quality

To understand effects of temperature on the yield and quality, a year-round field approach had been performed. Certain of threshold relationships among temperature, yield components, and quality traits were found. Results revealed that spikelet fertility was significantly binominal-correlated with temperature with the average daily temperature and daily maximum temperature at heading stage (Fig. 2). The threshold temperature affecting fertility was 26℃ for average daily temperature and 31℃ for daily maximum temperature [4]. Binominal correlations were also found between effective panicle number per hill and average daily temperature at tillering stage, with a threshold of 23℃.

In grain quality rate immature chalky grain rate was positively correlated to the average daily temperature during grain filling stage. Grain quality of the second crop is in general higher than that of the 1st crop, due to a lower temperature at the 2nd crop during grain filling stage (Fig. 3). Further experiments showed that immature brown rice was negatively correlated with the average daily temperature and maximum temperature within 15 days after heading, with threshold at 22℃ and 26℃ respectively. A similar correlation and threshold were also found between rate of chalky milled rice and the average daily temperature and maximum temperature within 15 days after heading. Accumulation temperature above 26℃ within 15 days after heading can be used as an index for the extent of rate immature or chalky grains.

Quality has been the main focus of rice improvement. It is important to estimate the effects of high temperature on quality traits. Results of our year round field experiments suggested the negative relationship between average temperature within 15 days after heading and amylose content, breakdown value, and peak viscosity value. High temperature may result in a relative lower yield but a higher palatability analyzer score of rice grains, due to mainly the lower amylose content [1].

The above identified temperature threshold or relationship can be used as key reference for designing the 'safe' culture period or breeding indexes of rice for coping with the warming trend of Taiwan [1, 4].

6. Adaptation of culture management in response to climate change

Rice farmers of Taiwan may already adjust their culture management in coping with the trend of warming. Statistic survey showed that the average temperature and maximum temperature have been increasing during recent 10 years for both crop seasons (Fig. 4). The increased temperature might cause a increase of immature/chalky grain rate. It is interested to note that farmers may already 'feel' the trend of climate warming. Our statistic review revealed that the timings of transplanting for the 1st crop and 2nd crop are also moved earlier in recent 10 years, especially in the main rice production regions of Taiwan (Fig. 4) [6]. The adjustment may lead to a lower temperature environment for grain filling stage of both crop seasons, and result in a 'stable' yield and quality [4].

7. Adaptation of cultivars and breeding

Since the vast introducing of japonica type varieties and successful breeding programs in Taiwan, at the present more than 90% cultivars belong to japonica type. Taiwan has become the lowest latitude region where japonica rice is dominantly cultivated. Grains produced by Taiwan's japonica type varieties have been named/called as 'Pon-lai rice', in order to differentiate them from grains produced by the traditional japonica varieties from Japan. The japonica varieties bred in Taiwan are thought to have less photoperiod sensitivity and higher warm temperature adaptation [5].

To compare the response of grain quality and yield to temperature, several cultivars bred from Taiwan or Japan were planted in the same years at Taiwan and Japan (Tsukuba). Results showed that Taiwan cultivars have a better yield stability between two culture locations, which may be due to the less photoperiod sensitivity of the cultivars. Taiwan cultivars, however, have less stability of grain quality traits than did the premium Japan cultivar Koshihikari. Cultivars grown in Taiwan had higher rate of dead grains and less amylose content than those same cultivars grown in Japan (unpublished).

Currently breeding program for high temperature tolerance is still at its infancy in Taiwan. Preliminary results from screening trails at phytotron reveal that almost all of modern cultivars are vulnerable to high temperature (35/30 ℃ of day/night, for two weeks after heading). Low spikelet fertility and high chalky rate are main factors for the low grain yield and quality in response to high temperature [1]. Introduction of related genes abroad is necessary to improve the high temperature tolerance. An ideotype was proposed for the breeding improvement of high temperature tolerance of Taiwan japonica cultivars [5].

8. Conclusion

In general japonica type varieties are adapted to temperate climate region. After more than 80 years breeding efforts, Taiwan japonica type varieties already adapted to the subtropical climate environment. Significant warming trend has been occurred and appeared by data from the past and projection for the future. Modification of culture management may confer the adaptation for a short term. Vigorous breeding program should be implemented to adapt the climate in the long term.

Just like that global climate change can not be mitigated without international cooperation, a global working network is necessary to assure stable production for every rice culture countries.

9. References

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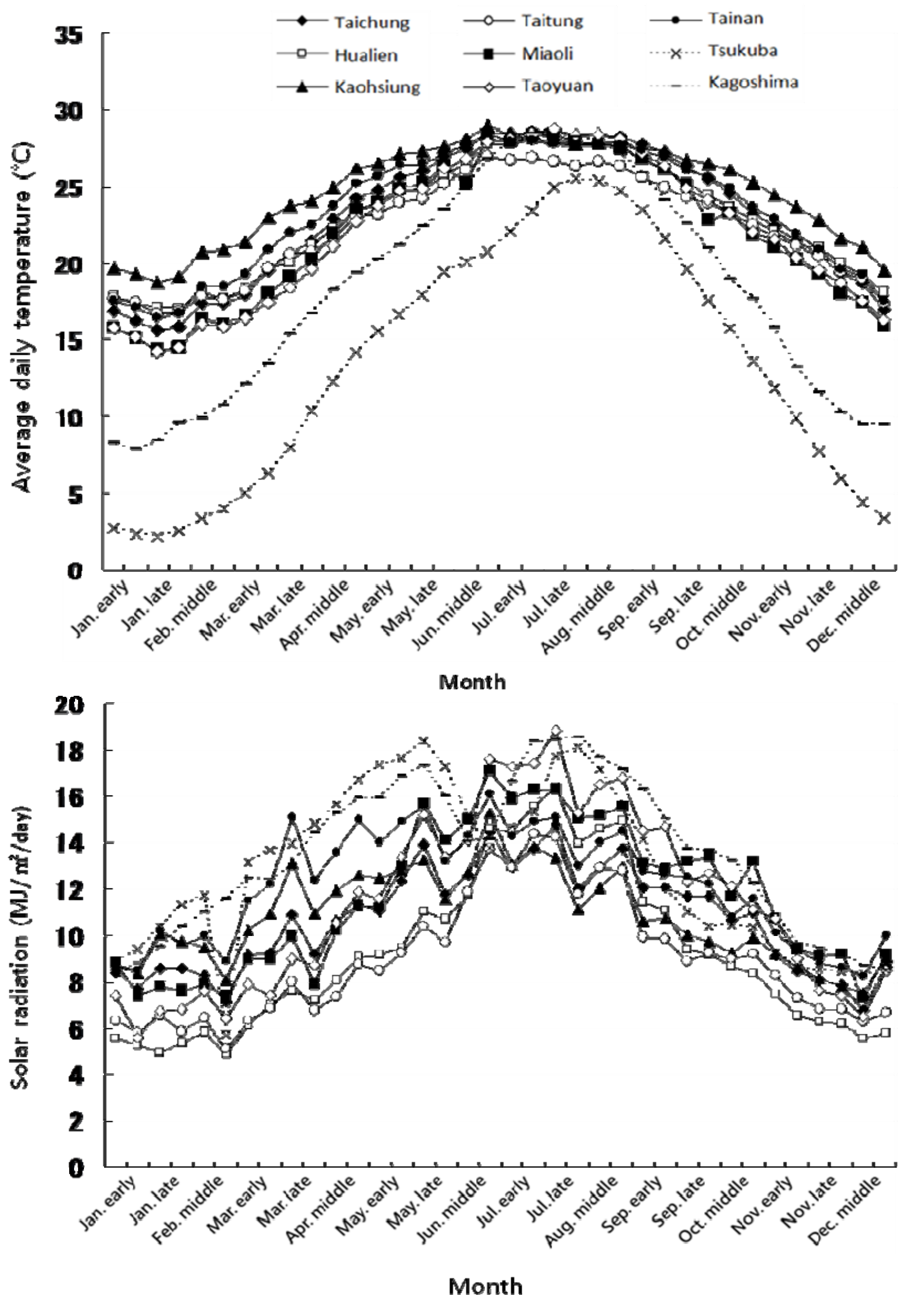

Figure 1. Comparison of fluctuations of annual average daily temperature (upper) and solar radiation (bottom) of seven locations of Taiwan and Japan (Tsukuba and Kagoshima). Adopted from reference [5].

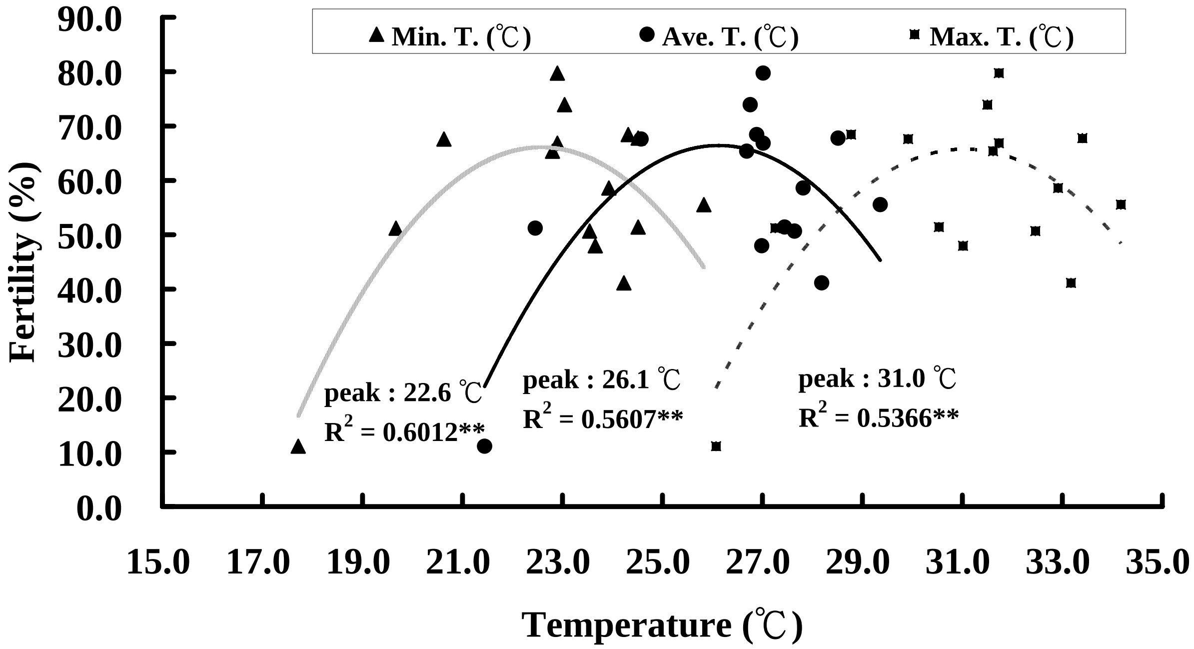

Figure 2. Relationship between panicle fertility and temperatures of the heading week. Data were analyzed from a two-years round field experiments with 16 transplanting dates conducted at MiaoLi District Research and Extension Station, Taiwan (2007 to 2008).

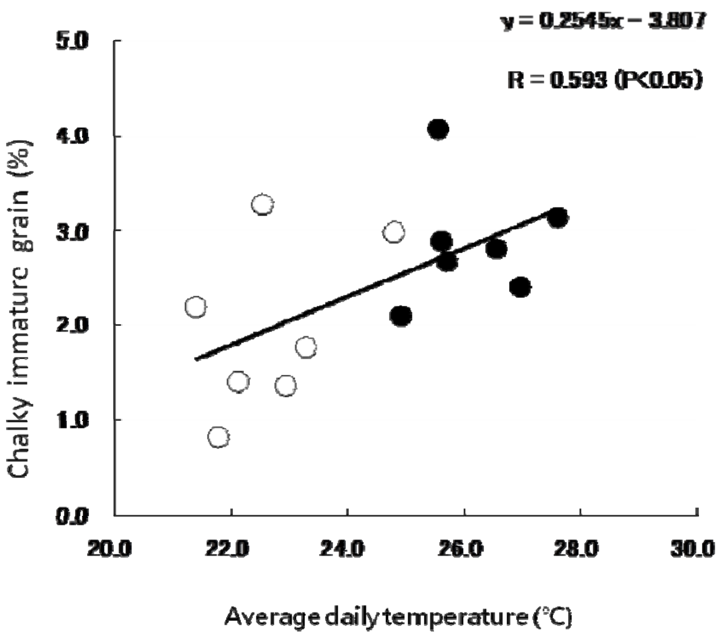

Figure 3: Correlation between chalky immature grain ratio and average daily temperature.
●: grains with the filling stage in May to June (the 1st crop of Taiwan);
○: grains with the filling stage in October to November (the 2nd crop of Taiwan). Adopted from reference [5].

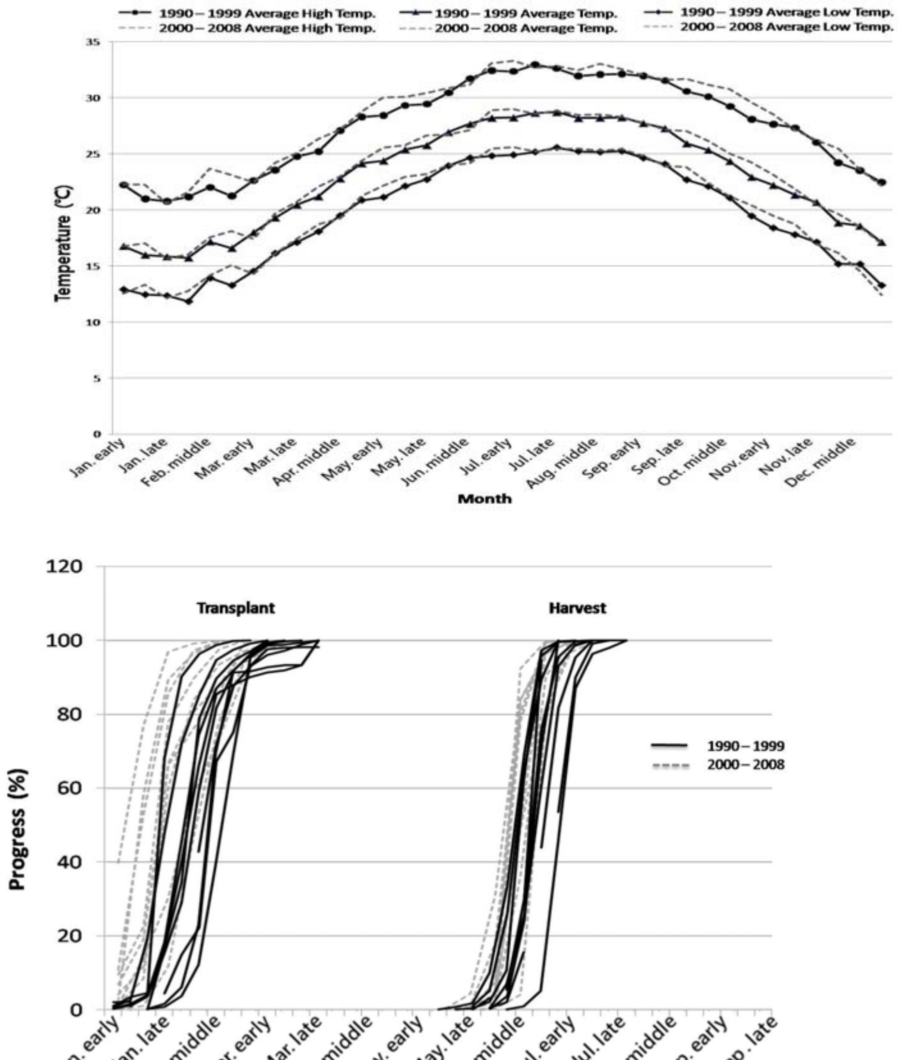

Figure 4 . Upper: Change in the average daily temperature between period 1990-1999 and 2000 -2008. Bottom: Changes in the timing of transplanting and harvest of the 1st crop among periods 1990-1999 and 2000 -2008; every data line refers to the progress of transplanting or harvest of one specific year.