

Research on Heat Stress of Rice in China: Progress and Prospect

Xiaohai TIAN, Haiwei LUO, Hengduo ZHOU
Yangtze University
88 Jingmi Rd, Jingzhou, Hubei 434025, P.R. China;
xiaohait@sina.com

Abstract: There have been six times of severe heat damages happened to the mid-season rice in Yangtze River Valley (YRV), China during the past 50 years, with the latest one occurred in 2003. It was estimated that the involved acreage of rice in 2003 was about 3 million ha, with a loss of about 5.18 million rice grain yields. The serious heat stress situation in YRV might be closely correlated with the characteristic climatic environment of this area, as well as some hybrid rice cultivars commercialized here which showed likely more susceptible to heat stress. From 2003 on, heat stress of rice in YRV has gradually become a highlight issue in Chinese crop science. The current researches focus on, 1) identifying on-farm micro-meteorological factors with heat stress; 2) the meteorological pattern for heat stress weather formation and its forecasting; 3) facilities and methods for germplasms and cultivars screening; 4) breeding-related researches; 5) cellular and biochemical processes underlining heat stress injury.

Key words: rice; heat stress; high-temperature; Yangtze River Valley; hybrid rice

1. Research Background

China is the largest country in rice production and rice consumption over the world. The annual acreage of cultivation with rice was estimated at 28.8 million ha, accounting for 27% of the total acreage of cultivated cereal crops; the total rice grain production was 181.0 million tones, with an average grain yield of 5.75 t/ha, and accounting for 43% of the total cereal grain production. The rice cropping belt along the Yangtze River Valley (or YRV) is the largest belt in China, occupying 70% of the total rice growing areas. While nearly 40% of the rice planted here belongs to the so-called mid-season *Indica* hybrid rice, with its reproductive and flowering stages sitting coincidentally around late-July to August, when in this region the hottest weather of a year occurs. Global warming has been likely to induce more frequently and severely extreme, hot weather or heat stress, which has consequently induced rice sterility, resulting in serious yield reduction, thus threatening the security of rice and then grain production in China^[6, 18].

2. Occurrence and Damages

Serious heat stress events and damages in rice have occurred in 1959, 1966, 1967, 1978, 1994 and 2003 along the YRV, of which only the last three events have been recorded in scientific literature^[4, 5, 17, 20]. Heat stress in rice started to become a serious concern for rice production in 1978, when hybrid rice area rose rapidly in China and it showed more likely sensitivity to heat stress. As it is known, China began to commercialize the hybrid rice in 1976. Only two years later, a rare heat stress befell in the summer in Hubei and Sichuan provinces. Seed set rate of some cultivars then dropped to less than 50%, and some very heat stress-sensitive ones even dropped to about 10% (cf. the normal rate of 85–90%). The low seed set rate for hybrid rice following the heat stress has thus attracted vast attention immediately. In 1994, an extremely high temperature event happened again. The seed set rate of some hybrids, such as “II you 63”, dropped to less than 10%. The heat stress occurred in 2003 might have been the severest heat shock in the history of rice cropping for the region, in terms of both the duration and the magnitude of the heat stress^[8]. All mid-season rice for the region has suffered from the heavy hit with no exception. Rice yield harvested in 2003 thus dropped to the lowest point of its past 20 years for the region.

Detailed data for the losses from the disaster has been incomplete. It was however reported that in Anhui Province alone, the heat stress affected an area of 0.33 million ha, accounting for 17% of its total rice-growing area^[5]. In Wuhan area of Hubei Province, heat stress affected an area of 27,000 ha, about 48% of its total rice-growing area, with 50% of yield loss as against a normal year. It was estimated that the involved acreage of rice in 2003 was about 3 million ha, with a loss of about 5.18 million tonnes of rice grain yields. Surveys of affected rice field revealed that those apparently injured plants set seeds ranging 10%–70%, with a majority being 40–60%^[8].

Moreover, multiple-sowing experiments with various cultivars from 2004 in Yangtze University, the middle reaches of Yangtze, showed that moderate heat injury happened four times within 5 years to the mid-season rice plants.

3. Brief History and Progress

The history of rice heat stress research is quite short with only about 30 years in China. However, we would like to classify the short episode into three stages: the first stage (1971–1986), or the initial stage, when the first-generation hybrid rice was affected by heat stress and some field observations were made^[7, 9, 11, 13, 21, 27]; the 2nd stage (1987–2003), or the application research stage, during which some controlled experiments were made and screening for germplasm tolerance began^[23]; the 3rd stage (from 2004 to present), or the comprehensive research stage, when a range of researches are undertaken, including the identification of micro-meteorological conditions, morphology of anther and pollen, physiological response of strains to heat stress, evaluation facilities and methods, germplasm use and breeding. A Sino-Nippon cooperative group has worked on field rice heat stress in Yangtze University for years during this stage.

A brief history about the research under discussion was examined by searching literatures of published articles and/or papers from available information sources or database. A searching of the National Academic Knowledge Index (CNKI) in China for the period of 1979–2008 with key words of “rice; heat stress” returned 100 papers. Whilst for the period of 1979–2002, only 27 papers were retrieved. In contrast, for the period of 2003–2008, the number of papers retrieved jumped to 73. Worth noting is that 95% of the papers were produced by those geographically from the YRV. Similarly, during the period of 1979–2002, no single dissertation was retrieved, while for the period of 2003–2008 a total of 21 papers (5 of which were PhD theses) were retrieved. Again, 90% of those were produced by authors geographically along the YRV.

4. Achievements and Prospect

1) Micro-meteorological conditions for on-farm heat stress in rice in YRV

Tian et al. (2008) analyzed the field observational data of the year 2003, and outlined the likely micro-meteorological conditions under which field heat stress occurred^[15]. ① from the meiosis to anthesis stage of rice reproduction, during which there were 3–5 consecutive high-temperature days with a daily average temperature of $\geq 30^{\circ}\text{C}$ or a daily maximum temperature of $\geq 35^{\circ}\text{C}$; ② the night temperature reached to 29°C ; ③ the RH dropped from about 80% to about 60%^[16]; ④ the wind velocity was $\leq 1\text{m/s}$ or =0. These results may serve as a basis for meteorological parameters design in tolerance screening.

2) The meteorological pattern for heat stress weather formation and its forecasting

Some studies on meteorological pattern for climatic mechanisms in the event of 2003 summer set a basis for heat stress weather forecasting in the future. Yang and Li (2005) pointed out that this severe hot climate was directly affected by the extremely intensive and western extension of the subtropical high pressure in the western Pacific Ocean, which was associated with the global warming^[22]. Meanwhile, Ding et al. (2007) indicated that the Qinghai-Tibetan Plateau high pressure was somewhat associated with the occurrence of high temperature weather in southern YRV^[3]. Moreover, some studies suggested a tendency of this type of extreme temperature, in terms of frequency and magnitude of occurrence, being either the same or higher in the future.

3) Facilities and methods for germplasms and cultivars screening

In the 1990s, China National Rice Research Institute evaluated 320 new rice strains for their tolerances to heat stress under greenhouse conditions. On the other hand, scientists with Huazhong Agricultural University have focused their work on evaluating germplasms in phytotron. They are now able to use an hourly-set temperature and humidity regime to screen genetic materials^[2, 23]. This method was suggested for use in studies of small-scale evaluation. Infrared heater was recently used in controlled experiments in Nanjing Agricultural University and Yangtze University^[25].

4) Breeding-related researches

From long-term field observation and/or phytotron screening, many cultivars and germplasms with desirable characteristics in response to heat stress have been found^[10, 19, 26]. It is believed that heat stress-responding trait of rice is a quantitative trait and controlled by multiple genes with complicated gene interactive effects. Cao et al. (2003) detected 6 QTLs for this trait, for example^[1]. Zhang et al. (2009) screened heat stress-related genes with the method of microassay^[14].

5) Cellular and biochemical processes underlining heat stress injury

Many observations were made in relation to various species, cultivars, strains and treatments at specific reproductive stages^[12, 14].

Nevertheless, the research on rice heat stress in China has just begun. Topics and/or issues entailing further studies and need to be addressed are briefed below.

Little is known of the cellular, biochemical and molecular processes for anther or pollen formation under field condition when heat stress occurs, which has greatly obstructed the research in cultivar evaluation and molecular analyses.

In order to breed and develop new cultivars, multiple-scale and multi-purpose screening and evaluation methods for elite, tolerant materials need to be established.

Effective methodologies to select and incorporate heat stress tolerance to parental lines of hybrid rice breeding have to be developed.

On-farm techniques or farming practices to protect crops from heat stress and methods for precise forecasting of extreme weather are urgently needed.

5. References

- [1] Cao L-Y, Zhao J-G, Zhan X-D, LI D-L, He L-B, Cheng S-H. 2003. Mapping QTLs for heat tolerance and correlation between heat tolerance and photosynthetic rate in rice. *Chinese J Rice Sci*, 17 (3) :223-27. (In Chinese with English abstract)
- [2] Chen Q-Q, Wan B-L. 2009. Study On Phytotron Identification Method Of Rice Heat Tolerance. *J Anhui Agri Sci*, 37(14): 6350-6351. (In Chinese with English abstract)
- [3] Ding H-J, Zhou L-L, Zha B, Zhai G-Q. 2007. An analysis on the abnormal high temperature weather in the south Yangtze Valley during summer 2003. *Journal of Zhejiang University (Science Edition)*, 34 (1):100-103(In Chinese with English abstract)
- [4] Fan G-T. 1979. The sterility of Nanyou 2 as a mid-season crop. *Hubei Agricultural Sciences*,18: 13-18.(In Chinese with English abstract)
- [5] Huang Y-D, Cao L-J, Wu L-Q, Yan P, Chen D-P, Yang A-Z. 2004. Investigation and analysis of heat damage on rice at blossoming stage in Anhui Province in 2003. *Journal of Anhui Agricultural University*, 31(04): 385-388(In Chinese with English abstract)
- [6] Li S H, Tian X H, Huang Y P, Liu A Y. 2007. Preliminary analysis of high temperature harm in middle-season rice at flowering stage in Jiangnan Plain in the latest 50 years. *Chinese Journal of Agrometeorology*, 28(1):5-8.(In Chinese with English abstract)
- [7] Li R-Q, Zeng Z-H, Liu L-H. 1980. Cytological observation of the formation and the development of pollens in rice stressed by high temperature. *Hubei Agricultural Sciences*, 19: 1-3 (In Chinese with English abstract)
- [8] Li C-Y, Peng C-H, Zhao Q-B, Xie P, Chen W. 2004. Characteristic analysis of the abnormal high temperature in 2003 midsummer in Wuhan city. *Journal of Central China Normal University (Natural Sciences)*, 38(03):379-381(In Chinese with English abstract)
- [9] Li Xunzhen, Liang Manzhong, Zhou Guangqia, Chen Liangbi. 2002. Effect of environmental condition on pollen vigor and seed set during flowing time of rice. *Acta Agronomica Sinica*. 28(3):417-420. (In Chinese with English abstract)
- [10] Lv C-G, Zou J-S, HU N, Yao K. 2005. Correlation of intersubspecific hybrid rice spikelet fertilization rate with temperature and related statistic model. *Chin.J.Appl.Ecol*. 16(6):1026-1032. (In Chinese with English abstract)
- [11] Ren Jiujiang.1979. Seed set decrease with high or low temperature in hybrid rice. *Meteorology*. 5:22-24. (In Chinese with English abstract)
- [12] Shi L-C, Jin Z-Q, Zheng J-K, Tang R-S. 2008. Quantitative analysis on the effects of high temperature at meiosis stage on seed-setting rate of rice florets. *Acta Agron Sin*, 34(4): 627-631 (In Chinese with English abstract)
- [13] Tan Z-H, Lan T-Y, Ren C-F, Fang W. 1985. Studies on high temperature injury on hybrid rice at flowering time and the strategy to avoid high temperature damage. *Acta Agron Sin.*,11:103-107. (In Chinese with English abstract)
- [14] Tang Risheng, Zheng Jianchu, Zhag Dadong, Jin Zhiqing, Chen Liugen, Huang Yihong, Shi Chunlin, Ge Daokuo. 2006. Effects of high temperatures on pollen vitality and seed setting of different rice varieties. *Jiangsu J. Agr. Sci.*, 22 (4) : 369-373. (In Chinese with English abstract)
- [15] Tian, X., Y. Huang, T.Matsui. 2008. Characterizing the rice field climatic factors under high temperature stress at anthesis. 5th International Crop Science Congress, PP19, April 13-18, Jeju, Korea
- [16] Tong Zhi-ting, Li Shou-hua, Duan Wei-xin, Deng Yun, Tian Xiao-hai. 2008. Temperature-driven climatic factors and their impact on the fertility of hybrid rice at anthesis. *Chinese J Eco Agri.*, 16 (5) : 1163- 1166. (In Chinese with English abstract)
- [17] Wang C-L, Zhong W-G. 2004. The effect of high temperature to rice seedset and its countermeasures. *Jiangsu Agri Sci*, 32(01): 15-18. (In Chinese with English abstract)
- [18] Wang Yawei,Zhai Panmao,Tian Hua.2006. Extreme high temperatures in southern China in 2003 under the background of climate change. *Meteorology*, 32(10): 27-32.(In Chinese with English abstract)
- [19] Xia mingyuan, Qi Huaxiong. 2004. Effects of high temperature stress on the setting rates of hybrid combinations using four steril lines. *Hubei Agricultural Sciences*. 43:21-22. (In Chinese with English abstract)
- [20] Xun C-Z, Yan S-C, Cai S-Y. 1982. Effect of high-temperature on the spikelet fertility of hybrid rice. *Journal of Huazhong Agricultural University*, 1: 1-7. (In Chinese with English abstract)

- [21] Yang S. 1985. Adapting hybrid rice to climate conditions for a high and stable yield. *Hubei Agri. Sci.*, 24(1):5-10.(In Chinese with English abstract)
- [22] Yang H, Li C-Y. 2005. Diagnostic study of serious high temperature over south China in 2003 summer. *Climatic and Environmental Research*, 10(1):80-85(In Chinese with English abstract)
- [23] Zeng H-L, Lu K-Y, He D-H, Pan X- X, Zhang D-P. 2000. The spikelet fertility of new mid-mature Indica hybrid rice combinations under high temperature conditions. *Journal Of Huazhong Agricultural University*,19(01):1-4(In Chinese with English abstract)
- [24] Zhang Xianwen, Ailing Liu, Jie Zou, Xiaoyun Zhou, Wenfang Wang, Liyun Chen, Xinyao Xiong, Xinbo Chen, 2008.12.31, Expression Profile of Young Rice Panicle under Heat stress using DNA Microarray. *Chin. Sci. Tech. Papers Online*, A200812-3129
- [25] Zhang B, Rui W-Y, Zheng J-C, Zhou B, Yang F, Zhang W-J. 2007. Responses of pollen activity and seed setting of rice to high temperature of heading period. *Acta Agronomica Sinica*,33(7):1177-1181. (In Chinese with English abstract)
- [26] Zhang G-L, Chen L-Y, Zhang S-T, Liu G-H, Tang W-B, Li M-H, Lei -Y, Chen X-B.2008. Effects of high temperature stress on pollen characters and anther microstructure of rice. *Acta Ecologica Sinica*, 28:1089-1096. (In Chinese with English abstract)
- [27] Zhu X-M, Zeng Q-X, Ning Q-L. 1983. Effect of natural high temperature on flowering and fertilization in hybrid rice. *Scientia Agricultura Sinica*, 16 (02): 37-44.(In Chinese with English abstract)