Tech Science Press

Article

Performance of Soft Rice (*Oryza sativa* L.) Grown in Early Season in China

Xiaohong Yin[1], Hengdong Zhang[1], Jiana Chen[1], Ruichun Zhang[2], Longsheng Liu[2], Min Huang[1,*], Guanghui Chen[1] and Yingbin Zou[1]

[1]Crop and Environment Research Center for Human Health, College of Agronomy, Hunan Agricultural University, Changsha, 410128, China

[2]Hengyang Institute of Agricultural Sciences, Santang, 421101, China

[*]Corresponding Author: Min Huang. Email: mhuang@hunau.edu.cn

Abstract: Eating quality is of paramount importance to rice (*Oryza sativa* L.) consumers and soft rice with low amylose content has become popular in China. This study was conducted to evaluate the performance of soft rice grown in the early season (ES) dominated by non-soft rice. Field experiments were conducted in Yongan and Santang, Hunan Province, China from 2016-2018. Results showed that grain amylose content in soft rice cultivars was consistently lower in the ES compared to the late season (LS). The lower grain amylose content in the ES compared to the LS was partly attributed to higher average daily mean temperature during grain filling. No significant relationship was observed between grain yield and seed amylose content in ES rice. Soft rice cultivars produced a similar average grain yield to non-soft rice cultivars in the ES. These results encourage breeders to develop more ES rice cultivars with soft texture to meet the consumer demand for this type of rice.

Keywords: Amylose content; early season rice; grain quality; grain yield

1 Introduction

Rice (*Oryza sativa* L.) is the staple food for more than 65% population in China [1]. To produce enough rice to meet the domestic need, improving yield has been the first priority in rice research and production in China for a long time [2]. However, in recent years, China's rice production has undergone an unprecedented period of transition due to changes in the socioeconomic and physical environments [3, 4]. In particular, the demand for high-quality rice has increased in China as people's living standards improved [5,6].

Double-season cropping with early season (ES) rice grown from late March (sowing) to late July (harvesting) and with late season (LS) rice grown from mid-June to late October is a common intensive rice cropping system in China that plays an important role in ensuring national food security [7]. However, in recent years, the planting area of ES rice has sharply decreased partly due to inferior rice quality [6], which is largely attributable to high temperature during grain filling period [8]. Therefore, it is important to improve the quality of ES rice to reverse the declining trend in planting area and to produce more high-quality rice.

Eating quality is one of the key aspects that affect rice consumers' acceptability. Soft rice with low amylose content (less than 15%) has become popular in China [9]. Consequently, many studies have been undertaken to better understand the genetic and agronomic aspects of soft rice in the last few years [9-11]. However, surprisingly, 83% and 91% of ES rice cultivars released in the past 15 years were non-soft rice with an amylose content of more than 15% in Hunan and Jiangxi, respectively (Fig. 1), the top two double-season rice producing provinces in China. This raises two questions: (1) whether the low amylose

content of soft rice is dependent on season; and (2) whether yield performance of ES rice is related to amylose content.

In the present study, field experiments were conducted during 2016-2018 with the goals of: (1) comparing the grain amylose content of soft rice cultivars between the ES and LS; and (2) evaluating the relationship between grain yield and seed amylose content in ES rice using soft and non-soft cultivars.
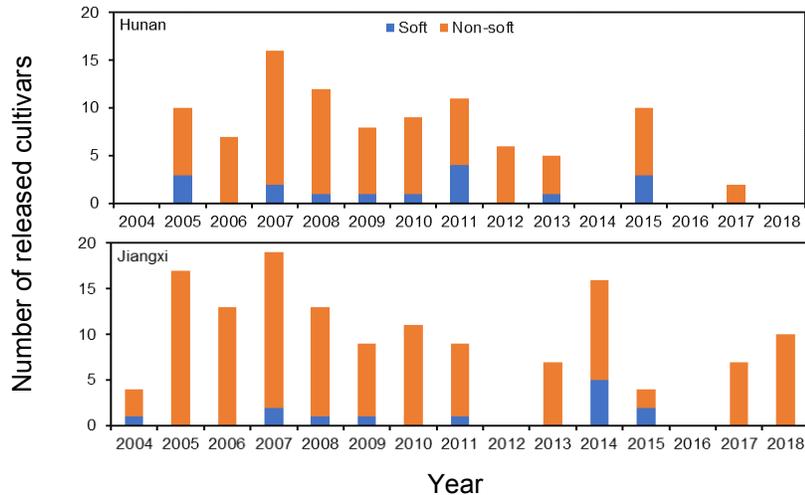

Figure 1: Number of soft and non-soft early season rice cultivars released in Hunan and Jiangxi, China from 2004-2018

2 Materials and Methods

2.1 Site and Soil

Field experiments were done in Yongan (28°09'N, 113°37'E, 43 m asl), Hunan Province, China with ES and LS rice in 2016 and 2017, and in Santang (26°53'N, 112°28'E, 71 m asl), Hunan Province for ES rice in 2017 and 2018. Both sites are in the main double-season rice producing region of Hunan Province. The soil of the experimental field had a clay texture in both sites. The soil properties at the 0-20 cm layer were: pH = 6.08, organic matter = 43.4 g kg^{-1}, and available N = 201 mg kg^{-1} in Yongan; and pH = 5.86, organic matter = 31.0 g kg^{-1}, and available N = 145 mg kg^{-1} in Santang.

2.2 Cultivars and Management Practices

Three soft rice cultivars, Linglingyou 268 (LLY268), Xiangzaoxian 42 (XZX42), and Xiangzaoxian 45 (XZX45) were used in the experiment in Yongan. Eight rice cultivars, including four soft rice cultivars (Lingliangyou 104, LLY268, XZX42, and XZX45) and four non-soft rice cultivars (Luliangyou 996, Zhuliangyou 819, Zhongjiazao 17, and Zhongzao 39) were used in the study in Santang. According to the cultivar information recorded in the China Rice Data Center (http://www.ricedata.cn), amylose content is 12-15% and 22-27% for the selected soft and non-soft rice cultivars, respectively; total growth duration averaged across cultivars is 110 d for both the soft and non-soft rice group. These cultivars have been widely grown by rice farmers in the study region. The cultivars were arranged in a randomized complete block design with three replications in both sites. The plot size was 40 m^2 in Yongan and 15 m^2 in Santang.

Rice seedlings were raised in trays in both sites. In Yongan, 23 and 15 days old seedlings were transplanted on 20 April and 23 July for ES and LS, respectively, with a PZ80-25 rice transplanter (Dongfeng Iseki Agricultural Machinery Co., Ltd., Xiangyang, China). In Santang, 25 days old seedlings were transplanted on 24 April with a 2ZGQ-8B (NSD8) rice transplanter (Suzhou Kubota Agricultural Machinery Co., Ltd., Suzhou, China). Transplanting was done at a spacing of 25 cm × 11 cm and 25 cm × 12 cm in Yongan and Santang, respectively. Missing plants were replanted by hand at 7 days after transplanting to ensure a uniform plant population. The plots received 135 kg N ha^{-1}, 67.5 kg P$_2$O$_5$ ha^{-1},

and 135 kg K_2O ha^{-1} for ES in Yongan and Santang, and 150 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1} for LS in Yongan. N fertilizer was applied in three splits: 50% as basal fertilizer (1 day before transplanting), 20% at early tillering (7 days after transplanting), and 30% at panicle initiation. P fertilizer was applied as basal fertilizer. K fertilizer was split equally as basal fertilizer and at panicle initiation. The experimental field was kept flooded from transplanting until 7 days before maturity. Insects, diseases, and weeds were intensively controlled by chemicals to avoid yield loss.

2.3 Sampling and Measurements

In Yongan, daily mean temperature during grain filling (from heading to maturity) was recorded using a Vantage Pro2 weather station (Davis Instruments Corp., Hayward, CA, USA). Grains were collected from 10 hills on the diagonal of the plot at maturity to determine amylose content. In Santang, amylose content in the rice seed was measured before sowing. Grains were harvested from a 5 m^2 area in each plot to determine grain yield. The amylose content was measured using the iodine-blue colorimetric method. In brief, about 2 g of rice flour (particle size < 0.25 mm) was dispersed with 1 ml of 95% ethyl alcohol and then gelatinized with 9 ml of 1 mol L^{-1} NaOH in a boiling water bath for 10 min. The gelatinized solution was diluted to 100 ml with distilled water after cooling to room temperature. The reaction solution was prepared by adding 5 ml of the above solution, 1 ml of 1 mol L^{-1} acetic acid, and 3 ml of color-developing agent (0.2% I_2 and 2% KI) into a 100 ml volumetric flask with about 50 ml distilled water and then shaken well and diluted to 100 ml with distilled water. After standing for 20 min, the absorbance of the reaction solution was determined at 620 nm with a SP-756 UV-VIS spectrophotometer (Shanghai Spectrum Instruments Corp., Shanghai, China). The grain yield was calculated by adjusting to a moisture content of 0.14 g H_2O g^{-1}.

2.4 Statistical Analysis

Statistical analysis was performed using Statistix 8.0 analytical software (Tallahassee, FL, USA). The seasonal differences in grain amylose content were analyzed by analysis of variance (ANOVA) followed by the least significance difference (LSD) test using the data collected in Yongan. The relationship between grain yield and seed amylose content was analyzed by linear regression analysis using the data collected in Santang.

3 Results and Discussion

Average grain amylose content across seasons and years was 14% for LLY268 and 15% for XZX42 and XZX45 (Fig. 2). Grain amylose content was lower for ES than LS for all three soft rice cultivars in 2016, and the difference was significant for XZX42 (Fig. 2). In 2017, all three soft rice cultivars had significantly lower grain amylose content in ES compared to LS rice (Fig. 2). These results indicate that the trait of low amylose content for soft rice can be better expressed in the ES than in the LS. This could be partly explained by the seasonal differences in temperature during grain filling. In this study, average daily mean temperature during grain filling was higher in the ES than in the LS by 6.0°C in 2016 and by 4.9°C in 2017 (Fig. 3). Zhong et al. [8] observed that increasing daily mean temperature during grain filling from 22°C to 32°C led to a significant reduction in grain amylose content in two soft rice cultivars in a chamber experiment. Furthermore, Ahmed et al. [12] found that reduced grain amylose content in rice grown at a daily mean temperature of 32°C compared to 22°C was attributable to a reduction in activity of granule-bound starch synthase, the sole enzyme responsible for amylose synthesis in cereal endosperm [13].
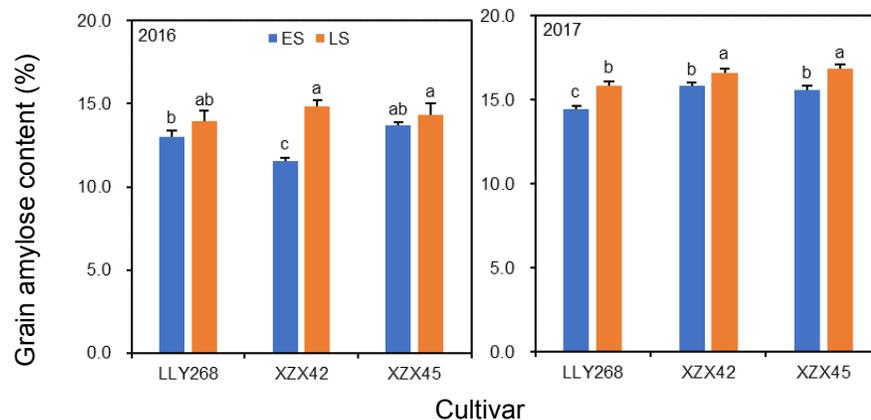
Figure 2: Grain amylose content in three soft rice cultivars grown in Yongan, Hunan Province, China in the early season (ES) and the late season (LS) in 2016 and 2017. Error bars represent SE (*n* = 3). Within a subfigure, bars not sharing any letter are significantly different by the LSD test at the 0.05 probability level
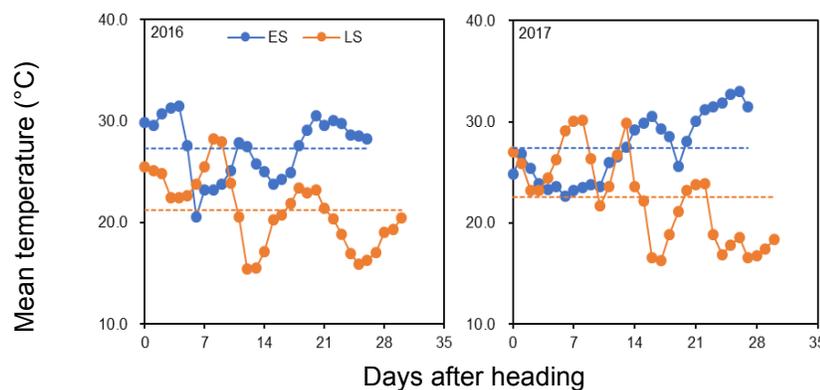

Figure 3: Daily mean temperature during rice grain filling period in Yongan, Hunan Province, China in the early season (ES) and the late season (LS) in 2016 and 2017

In addition, the results showed that grain amylose content in the ES varied between years (Fig. 2). However, the yearly difference in grain amylose content in the ES could not be explained by average daily mean temperature during grain filling. Namely, average daily mean temperature during grain filling in the ES was almost the same in 2016 (27.3°C) and 2017 (27.4°C), but grain amylose content in the ES was lower in 2016 than in 2017 for all three cultivars (Figs. 2 and 3). This yearly difference in grain amylose content might be related to the difference in daily mean temperature during the early grain filling period. Average daily mean temperature during the period of 0-5 days after full heading in the ES was 5.4°C higher in 2016 (30.1°C) than in 2017 (24.7°C). The early grain filling period is one of the critical periods for amylose synthesis in the rice grain [14]. These facts indicate that the approach of artificially controlling temperature at a constant value in previous studies [8,12] is limited because it does not necessarily reproduce natural conditions. Further investigations are required for greater fundamental understanding of the effects of high temperature during the early grain filling period on physiological processes governing amylose synthesis in rice grains.

There was no significant relationship between grain yield and seed amylose content across eight rice cultivars and two years (Fig. 4). Average grain yield across four cultivars and two years was similar for soft (8.06 t ha^{-1}) and non-soft rice (8.00 t ha^{-1}). These results demonstrate that soft rice can produce grain yield as high as non-soft rice in the ES. This finding is not in agreement with the view that high seed amylose content is beneficial for improving early vigor in rice plants [15], which is important for achieving high grain yield in ES rice because temperature is always low in the early period of the ES [16,

17]. This view might also be partly responsible for why breeders prefer to develop non-soft ES rice cultivars (Fig. 1). But in fact, rice is a crop with strong self regulating capacity: a low biomass produced during early growth period always results in an increase in biomass production during the late growth period [18]. Moreover, daily temperatures tend to increase during the ES. The negative effect of low temperature during the early growth period in the ES may be diluted with the advancement of growth process. These findings suggest that further studies are needed to compare the growth traits between soft and non-soft rice cultivars in the ES.
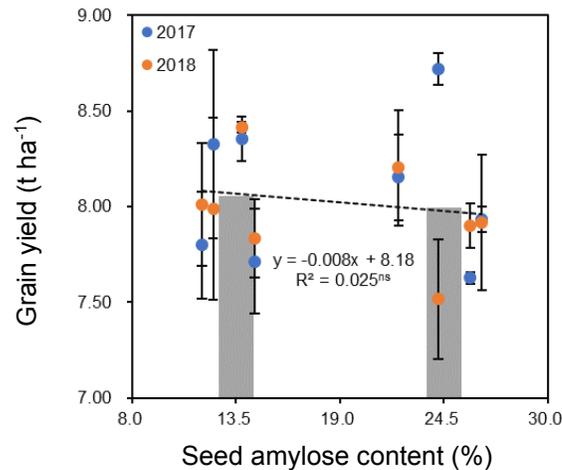

Figure 4: Relationship between grain yield and seed amylose content in early season rice. Data were obtained from field experiments in which eight rice cultivars, including four soft and four non-soft rice cultivars, were grown in Santang, Hunan Province in 2017 and 2018. Gray columns represent the average yield of soft and non-soft cultivars. [ns] denotes a non-significant relationship at the 0.05 probability level

Taken together, the results of this study encourage breeders to develop more ES rice cultivars with soft texture to meet the consumer demand for rice with desirable characteristics and consequently help to reverse the declining trend in the planting area of ES rice and ensure national food security in China. However, there is a limitation that must be acknowledged in our present study. We did not consider the effect of high temperature during grain filling period in ES on the milling and appearance quality in soft rice. Previous studies have showed that high temperature during grain filling period may accelerate grain filling rate and consequently result in loosely packed starch granules, decreased head milled rice rate, and increased abnormal and chalky rice rate [19-22]. Therefore, further investigations are required to overcome this limitation to obtain more comprehensive understanding regarding the performance of soft rice grown in ES.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

1. Hsiaoping, C. (2005). *Rice consumption in China: can China change rice consumption from quantity to quality.* In: *Toriyama, K., Heong, K. L., Hardy, B. (eds), Rice is life: scientific perspectives for the 21st century.* pp. 497-499. International Rice Research Institute, Los Baños, Philippines.

2. Peng, S., Khush, G. S., Virk, P., Tang, Q., Zou, Y. (2008). Progress in ideotype breeding to increase rice yield potential. *Field Crops Research, 108,* 32-38.

3. Peng, S., Tang, Q., Zou, Y. (2009). Current status and challenges of rice production in China. *Plant Production*

Science, 12, 3-8.

4. Peng, S. (2014). Reflection on China's rice production strategies during the transition period. *Scientia Sinica Vitae, 44,* 845-850.

5. Liao, X., Chen, Q., Pan, G. (2002). Status and strategies for improving high-quality rice production in China. *Journal of Agrotechnical Economics, 5,* 32-34.

6. Peng, S. (2016). Dilemma and way-out of hybrid rice during the transition period in China. *Acta Agronomica Sinica, 42,* 313-319.

7. Zou, Y. (2011). Development of cultivation technology for double cropping rice along the Changjiang River valley. *Scientia Agricultura Sinica, 44,* 254-262.

8. Zhong, L. J., Cheng, F. M., Wen, X., Sun, Z. X., Zhang, G. P. (2005). The deterioration of eating and cooking quality caused by high temperature during grain filling in early-season *indica* rice cultivars. *Journal of Agronomy and Crop Science, 191,* 218-225.

9. Yang, J., Wang, H., Fan, F., Zhu, J., Chen, T. et al. (2013). Development of AS-PCR marker based on a key mutation confirmed by resequencing of *Wx-mp* in milky princess and its application in *japonica* soft rice (*Oryza stativa* L.) breeding. *Plant Breeding, 132,* 595-603.

10. Li, J., Xu, S., Yang, L., Zhou, Y., Fan, S. et al. (2009). Breeding elite *japonica*-type soft rice with high protein content through the introduction of the anti-*Waxy* gene. *African Journal of Biotechnology, 8,* 161-166.

11. Zhu, D., Zhang, H., Guo, B., Xu, K., Dai, Q. et al. (2017). Effects of nitrogen level on yield and quality of *japonica* soft super rice. *Journal of Integrative Agriculture, 16,* 1018-1027.

12. Ahmed, N., Tetlow, I. J., Nawaz, S., Iqbal, A., Mubin, M. et al. (2015) Effect of high temperature on grain filling period, yield, amylose content and activity of starch biosynthesis enzymes in endosperm of basmati rice. *Journal of the Science of Food and Agriculture, 95,* 2237-2243.

13. Denyer, K., Johnson, P., Zeeman, S., Smith, A. M. (2001). The control of amylose synthesis. *Journal of Plant Physiology, 158,* 479-487.

14. Shi, C., Wu, J., Wu, P. (2005). Genetic analysis of developmental behavior for amylose content in filling process of rice. *Journal of the Science of Food and Agriculture, 85,* 791-796.

15. Huang, M., Zhang, R., Chen, J., Cao, F., Jiang, L. et al. (2017). Morphological and physiological traits of seeds and seedlings in two rice cultivars with contrasting early vigor. *Plant Production Science, 20,* 95-101.

16. Huang, M., Zhang, W., Jiang, L., Zou, Y. (2013). Impact of temperature changes on early-rice productivity in a subtropical environment of China. *Field Crops Research, 146,* 10-15.

17. Huang, M., Yang, C., Ji, Q., Jiang, L., Tan, J. et al. (2013). Tillering responses of rice to plant density and nitrogen rate in a subtropical environment of southern China. *Field Crops Research, 149,* 187-192.

18. Huang, M., Zou, Y., Jiang, P., Xia, B., Feng, Y. et al. (2012). Effect of tillage on soil and crop properties of wet-seeded flooded rice. *Field Crops Research, 129,* 28-38.

19. Yoshida, S., Hara, T. (1977). Effects of air temperature and light of grain filling of an *indica* and a *japonica* rice (*Oryza sativa* L.) under controlled environmental conditions. *Soil Sciences and Plant Nutrition, 23,* 93-107.

20. Resurreccion, A. P., Hara, T., Juliano, B. O., Yoshida, S. (1977). Effect of temperature during ripening on grain quality of rice. *Soil Sciences and Plant Nutrition, 23,* 109-112.

21. Tashiro, T., Wardlaw, I. F. (1991). The effect pf high temperature on kernel dimensions and the type and occurrence of kernel damage in rice. *Australian Journal of Agricultural Research, 42,* 485-496.

22. Lisle, A. J., Martin, M., Fitzgerald, M. A. (2000). Chalky and translucent rice grains differ in starch composition and structure and cooking properties. *Cereal Chemistry, 77,* 627-632.