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Comparison of Grain-Filling Characteristics Between Two Super Rice Cultivars with Remarkable Difference in Grain Weight

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Abstract: Two super rice cultivars, Zhunliangyou 527 with big grain (31.92 mg•grain^{-1}) and Yuxiangyouzhan with small grain (19.85 mg•grain^{-1}), were used to understand the factors that influence grain weight by comparing their grain-filling characteristics based on Logistic equation. Results showed that the potential values of superior, medium and inferior grain growths of Zhunliangyou 527 were higher than that of Yuxiangyouzhan, respectively. Moreover, the grain-filling rates, including initial grain-filling rates, maximum grain-filling rates and mean grain-filling rates, of the superior, medium and inferior grains in Zhunliangyou 527 were higher compared with those in Yuxiangyouzhan, respectively. However, the durations of the different grain-filling phases in the superior and medium grains of Zhunliangyou 527 were shorter than those of Yuxiangyouzhan. In addition, the starting and closing times of peak grain-filling stages and the times of maximum grain-filling rates of the superior and medium grains in Zhunliangyou 527 were earlier compared with those in Yuxiangyouzhan, whereas those of the inferior grains in Zhunliangyou 527 were later than those in Yuxiangyouzhan. Therefore, the larger sink capacity and higher grain-filling rates in Zhunliangyou 527 would lead to the bigger grain weight and it needs to be concerned as the asynchronous property of the grain-filling in the course of Zhunliangyou 527 cultivation.

Key words: Super rice · Grain weight · Sink capacity · Grain-filling rate · Grain-filling duration

INTRODUCTION

Super rice project of China was started in 1996 [1] and great achievements in super rice breeding have been made in recent years [2]. In 2005 ~ 2007, 61 cultivars with great yield potential had been approved as super rice by the Ministry of Agriculture, China [3]. However, how to make a full play of its yield potential and to further increase rice yield are still new topics for the development of the super rice [4]. Grain-filling ultimately determines the grain weight (*GW*) and rice yield, thus it is considered to be the most important physiological process of rice [5-7]. So far, some related studies have been conducted on the relationships of grain-filling rate (*GR*) and grain-filling duration (*GD*) to the *GW*, to explain the factors that influence the *GW*, however, the results are controversial [8-12].

Logistic equation is a prevailing used growth curve model and it has been widely used in simulating grain-filling processes of crops such as rice [8, 13-14], wheat [15-18] and maize [19, 20]. In the present study, the equation was used to simulate the grain-filling processes of superior, medium and inferior grains of two super rice cultivars, Zhunliangyou 527 and Yuxiangyouzhan, with remarkably different *GW*. Our objective was to understand the factors that influence the *GW* by comparing their grain-filling characteristics based on Logistic equation.

MATERIALS AND METHODS

Plant Materials and Experimental Design: Two indica super rice cultivars, Zhunliangyou 527 (big grain, average dry weight of grain: 31.92 mg•grain^{-1}) and Yuxiangyouzhan (small grain, 19.85 mg•grain^{-1}), were grown in the experimental field (latitude 28°11' N, longitude 113°04' E) of Hunan Agricultural University, central China's Hunan Province in 2008. The seeds were sown on 13 May and the seedlings were transplanted on 5 June with a density of one seedling per 20 cm × 20 cm area. The plot area was about 13.0 m^2 with 2 replications. Field management of fertilizer application, water irrigation and pest protection was done in the same way as the local field cultivation of high-yielding rice cultivars.

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At full heading stage (16 August), about 150 representative panicles were marked with white plastic plates (3.0 cm × 4.5 cm) and 10 of them were sampled in the next 2, 4, 8, 12, 16, 20, 26, 32 and 38 days, respectively. The superior, medium and inferior grains were picked from the samples based on the methods of Wang *et al.* [21]. Grains were weighted using an electronic balance after being dried at 80°C.

Grain Growth Equation and its Parameters: Grain-filling processes of superior, medium and inferior grains were fitted using Logistic equation:

$$y = \frac{k}{1 + e^{a-bx}} \quad (1)$$

where y represents observed GW, x represents days after full heading, k (estimate of potential value of grain growth), a and b are parameters of the equation.

Furthermore, some grain-filling parameters were deduced basing on the first and second order derivates from Eq. (1) [22]:

$$GR_0 = \frac{kbe^a}{(1+e^a)^2} \quad (2)$$

$$GR_{max} = \frac{kb}{4} \quad (3)$$

$$MGR = \frac{kb}{a\text{-}\ln(\frac{100}{99}\text{-}1)} \quad (4)$$

$$t_1 = \frac{a\text{-}\ln(2+\sqrt{3})}{b} \quad (5)$$

$$t_2 = \frac{a+\ln(2+\sqrt{3})}{b} \quad (6)$$

$$T_{max} = \frac{a}{b} \quad (7)$$

where k, a and b are the parameters of Eq. (1), GR_0 is initial grain-filling rate, GR_{max} is maximum grain-filling rate, MGR is mean grain-filling rate (grain-filling was considered to be complete when y = 99%k), t_1 is starting time of peak grain-filling stage, t_2 is closing time of peak grain-filling stage and T_{max} is time of maximum grain-filling rate.

In addition, the grain-filling processes were divided into three phases (prophase, metaphase and anaphase, respectively) and the GD (GD_1, GD_2 or GD_3) and MGR (MGR_1, MGR_2 or MGR_3) of each phase were calculated [23]:

$$GD_1 = \frac{a\text{-}\ln(2+\sqrt{3})}{b} \quad (8)$$

$$GD_2 = \frac{2\times\ln(2+\sqrt{3})}{b} \quad (9)$$

$$GD_3 = \frac{\text{-}\ln(\frac{100}{99}\text{-}1)\text{-}\ln(2+\sqrt{3})}{b} \quad (10)$$

$$MGR_1 = \frac{\frac{k}{1+e^{\ln(2+\sqrt{3})}}}{\frac{a\text{-}\ln(2+\sqrt{3})}{b}} \quad (11)$$

$$MGR_2 = \frac{\frac{k}{1+e^{\text{-}\ln(2+\sqrt{3})}}\text{-}\frac{k}{1+e^{\ln(2+\sqrt{3})}}}{\frac{2\times\ln(2+\sqrt{3})}{b}} \quad (12)$$

$$MGR_3 = \frac{\frac{k}{1+e^{\ln(\frac{100}{99}\text{-}1)}}\text{-}\frac{k}{1+e^{\text{-}\ln(2+\sqrt{3})}}}{\frac{\text{-}\ln(\frac{100}{99}\text{-}1)\text{-}\ln(2+\sqrt{3})}{b}} \quad (13)$$

where k, a and b are the parameters of Eq. (1).

RESULTS AND DISCUSSION

Grain-filling processes of superior, medium and inferior grains of Zhunliangyou 527 and Yuxiangyouzhan could be well simulated by Logistic equation with correlation coefficients ranged from 0.9760 to 0.9938 ($p < 0.001$; Table 1). However, there occurred differences in the parameters of the equations for Zhunliangyou 527 and Yuxiangyouzhan, especially in k. In Zhunliangyou 527, the k of the superior, medium and inferior grains were 49.59%, 49.54% and 60.08% higher than those in Yuxiangyouzhan, respectively. It revealed that Zhunliangyou 527 has stronger sink capacity. In rice, the sink capacity means ability of grain to receive assimilation products, which plays a key role in the grain-filling [24].

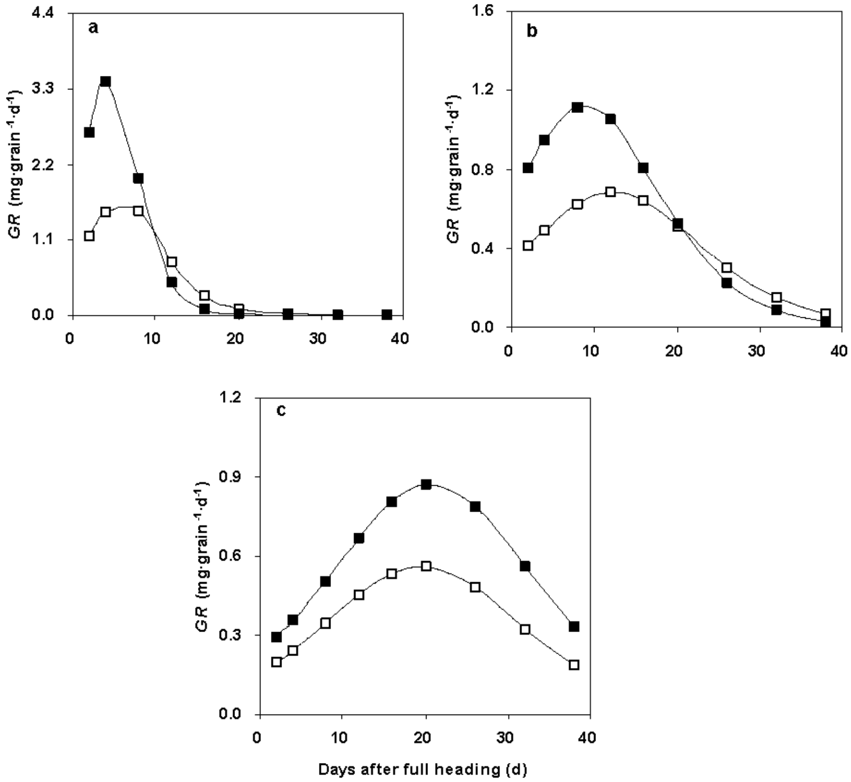

Fig. 1: Grain-filling rate (*GR*) of superior (a), medium (b) and inferior grains (c) in Zhunliangyou 527 (■) and Yuxiangyouzhan (□)

Table 1: Parameters of Logistic equation for grain-filling processes of Zhunliangyou 527 and Yuxiangyouzhan

Grain positions	Cultivars	*k*	*a*	*b*	R^2
Superior	Zhunliangyou 527	31.9786	1.8930	0.4303	0.9938***
	Yuxiangyouzhan	21.3781	1.8760	0.3096	0.9760***
Medium	Zhunliangyou 527	28.6980	1.6638	0.1867	0.9796***
	Yuxiangyouzhan	19.1913	1.7545	0.1425	0.9838***
Inferior	Zhunliangyou 527	28.5753	2.5223	0.1218	0.9813***
	Yuxiangyouzhan	17.8501	2.4706	0.1257	0.9900***

*** Significant at 0.001 probability level

Therefore, the difference in the sink capacity could be one of main factors that result in the discrepancy of *GW* between Zhunliangyou 527 and Yuxiangyouzhan.

On the other hand, the *GW* could be expressed as $GW = \int GR(t)dt$, namely time (*t*) integration for the *GR* [8], which implied that both enhancing the *GR* and prolonging the *GD* could increase the *GW*. In this study, the GR_0, GR_{max}, *MGR* of Zhunliangyou 527 were 106.58%, 108.48% and 107.84% higher than those of Yuxiangyouzhan in the superior grains, 111.76%, 97.06% and 100.00% in the medium grains and 50.00%, 55.36% and 53.13% in the inferior grains, respectively (Fig. 1 and Table 2). Furthermore, the MGR_1, MGR_2 and MGR_3 of Zhunliangyou 527 were obviously higher than those of Yuxiangyouzhan in the superior, medium and inferior grains (Table 3). However, the GD_1, GD_2 and GD_3 of Zhunliangyou 527 were 25.97%, 28.08% and 28.05% shorter than those of Yuxiangyouzhan in the superior grains and 39.41%, 23.65% and 23.65% in the medium grains, respectively (Table 3). All these indicated that the difference in *GR* would result in the discrepancy of *GW* in different cultivars and this was one of the main factors. Differently, some studies on japonica rice showed that the *GD* was the main factor [8, 9]. One

Table 2: Grain-filling parameters for Zhunliangyou 527 and Yuxiangyouzhan

Grain positions	Cultivars	GR_0 (mg•grain^{-1}•d^{-1})	t_1(d)	t_2(d)	T_{max}(d)	Gr_{max} (mg•grain^{-1}•d^{-1})	MGR (mg•grain^{-1}•d^{-1})
Superior	Zhunliangyou 527	1.57	1.34	7.46	4.40	3.44	2.12
	Yuxiangyouzhan	0.76	1.81	10.31	6.06	1.65	1.02
Medium	Zhunliangyou 527	0.72	1.86	15.97	8.91	1.34	0.86
	Yuxiangyouzhan	0.34	3.07	21.55	12.31	0.68	0.43
Inferior	Zhunliangyou 527	0.24	9.90	31.52	20.71	0.87	0.49
	Yuxiangyouzhan	0.16	9.18	30.13	19.65	0.56	0.32

GR_0, Initial grain-filling rate; t_1, Starting time of peak filling stage; t_2, Closing time of peak filling stage; T_{max}, Time of maximum grain-filling rate; GR_{max}, Maximum grain-filling rate; MGR, Mean grain-filling rate

Table 3: Grain-filling parameters for different phases of Zhunliangyou 527 and Yuxiangyouzhan

		Prophase		Metaphase		Anaphase	
Grain positions	Cultivars	GD_1 (d)	MGR_1 (mg•grain^{-1}•d^{-1})	GD_2 (d)	MGR_2 (mg•grain^{-1}•d^{-1})	GD_3 (d)	MGR_3 (mg•grain^{-1}•d^{-1})
Superior	Zhunliangyou 527	1.34	5.05	6.12	3.02	7.62	0.85
	Yuxiangyouzhan	1.81	2.50	8.51	1.45	10.59	0.41
Medium	Zhunliangyou 527	1.86	3.26	14.11	1.17	17.56	0.33
	Yuxiangyouzhan	3.07	1.32	18.48	0.60	23.00	0.17
Inferior	Zhunliangyou 527	9.90	0.61	21.62	0.76	26.91	0.21
	Yuxiangyouzhan	9.17	0.41	20.95	0.49	26.08	0.14

GD_1, MGR_1, GD_2, MGR_2, GD_3, MGR_3 represent grain-filling duration and mean grain-filling rate in prophase, metaphase and anaphase, respectively

reason for this difference might be discrepancies in varietal characteristics between indica and japonica. Past studies have shown that the cultivars of indica and japonica were two types with rather distant relationship in botany [25]. Besides, different environment conditions also might be the reason. Milka *et al.* [26] have demonstrated that the mutual impact of *GD* and *GR* on the *GW* was not the same in diverse environments. Therefore, a better understanding of the relationships of *GR* and *GD* to the *GW* in various climatic conditions, are needed to explain the factors that influence the *GW* in rice.

In addition, the results of the present study showed that the t_1, t_2 and T_{max} of the superior and medium grains in Zhunliangyou 527 were earlier compared with those in Yuxiangyouzhan, respectively. Reversely, those of the inferior grains in Zhunliangyou 527 were later than those in Yuxiangyouzhan (Table 2). It revealed that asynchronous property of the grain-filling in Zhunliangyou 527 was more apparent than that in Yuxiangyouzhan and this needs to be concerned in the course of Zhunliangyou 527 cultivation. Many previous studies showed that hybrid rice is characterized by phenomenon of contradiction between source and sink [27-29] as well as earlier leaf senescence [30-32] and it might be the reasons for the asynchronous property. Moreover, some studies named the asynchronous property as Apical-grain Superiority or Inter-grain Apical Dominance [33-35], which had a close relationship with difference of endogenous IAA content among different grain positions and suggested that it could be regulated by exogenous hormones.

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