INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
18F–038/2018/20–7–1650–1656
DOI: 10.17957/IJAB/15.0703
http://www.fspublishers.org

Full Length Article

Grain Filling Characteristics of Maize Hybrids with Different Maturity Periods

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Abstract

A field experiment was conducted at Shenzhou of Hebei province to study on grain-filling characteristics of maize hybrids differing in maturities, aimed to provide scientific information for the regulation of grain weight and selection of maturity. Four maize hybrids differing in maturities were used as experimental materials, under the same planting density. The main results were as follows. All the hybrids reached the maximum value of 100 grain fresh weight at 40d after pollination, and then declined slowly. The maximum value of 100 grain fresh weight of middle-maturity hybrid Zhengdan958 was the highest, and early maturity hybrid Demeiya1 was the lowest. After 40 days of pollination, all the hybrids reached the maximum value of 100 seed fresh weight, and then declined slowly, and the maximum 100 fresh weight of middle-late hybrid Zhengdan958 was the highest, and early-maturity hybrid Demeiya1 was the lowest. Four hybrids of 100 grain dry weight and fresh weight showed the same trend, it was a rapid growth period at 40d after pollination, the 100 grain dry weight of Hengyu1182 was maximum, Demeiya1 was minimum. The grain-filling rate of four hybrids showed a single peak curve, reached the maximum peak at 20d after pollination, the peak performance of four maize hybrids showed that Hengyu1182> Zhengdan958> Nongda108 > Demeiya1. The percentage of grain water of Hengyu1182 was the lowest, the value was 25.70% when 60d after pollination, Nongda108 was significantly higher than the other three hybrids ($P<0.05$), the value was 34.01%. The grain-filling processes of maize hybrids differing in maturities were analyzed by Logistic model, and the total filling period could be divided into early stage, middle stage and late stage. Middle-early hybrid Hengyu1182 showed that grain weight of every stage (W_1-W_3), and mean grain-filling rate of every stage (P_1-P_3) were higher than other three types. The results showed that the increase of grain weight was related to grain filling rate at filling stage, and the middle-early maturity hybrids suitable for planting in Heilonggang area.

Keywords: Pollination; Summer maize hybrids; Yield; Logistic equation; Heilonggang river valley

Introduction

Maize is an important feed resource, industrial raw material and food crop around the world and it occupies an important position in agricultural production (Duvick, 2005; Ali *et al*., 2014; Xiao *et al*., 2016). Heilonggang river valley is located in the south of Hebei province, it is the main planting area of summer maize in China (Zhao and Yang, 2018). The traditional planting pattern in this area is wheat-maize double cropping (Yang *et al*., 2014; Yan *et al*., 2016). Local farmers harvested maize early in order to plant winter wheat in October when they were not fully mature, resulting in varying degrees of yield loss in middle-late and late-maturing maize hybrids. In the later period of maize growth, the light and heat resources in the Heilonggang river valley were relatively tight. After the maize was harvested, the maize grain became moldy because it could not be natural wilting under safe moisture, which affected the quality of the product (Zhao *et al*., 2016). Therefore, choosing suitable maturity maize hybrids is one of the key elements of the maize yield increasing in the Heilonggang river valley. Some research reports pointed out that the increase of maize yield is mainly through the increase of planting density rather than the improvement of heterosis (Duvick *et al*., 2004; Assefa *et al*., 2016). Grain yield of maize was determined by grain number per unit area and grain weight, and grain weight was affected by grain filling rate and grain filling time. The grain filling process affects the final grain weight, yield and quality of maize and is the important biological processes of growth and development

To cite this paper: Yue, H., Y. Li, C. Li, J. Bu, J. Wei, A. Guo, S. Chen, H. Peng, J. Xie and X. Jiang, 2018. Grain filling characteristics of maize hybrids with different maturity periods. *Int. J. Agric. Biol*., 20: 1650–1656

(Zhang *et al*., 2013; Celaleddin *et al*., 2016; Chen *et al*., 2016). At present, there are many hybrids of corn of different maturing seasons in the Heilonggang Valley, and the yield levels differ greatly. In terms of production, the region has a habit of harvesting wheat in advance to harvest corn, often due to the late low temperature during late growth of corn, which prevents the maturity of late-maturing corn hybrids, resulting in serious production cuts. Therefore, the selection of suitable mature maize hybrids is one of the key factors for the continuous increase of maize production in Heilonggang area. A growing number of studies have shown that the increase in maize production is mainly due to increased planting density rather than increased heterosis (Duvick *et al*., 2004; Assefa *et al*., 2016). Maize grain yield is determined by the number of grains per unit area and grain weight. The grain weight depends on the grain filling duration time and the grain filling rate. The process of grain filling affects the final grain weight, yield and quality. It is an important biological process for the growth and development of maize. Studying the grain filling characteristics not only helps deepen the understanding of the process of grain weight formation, but also helps to take effective measures against key processes of grain filling, and control measures to achieve high yield and quality (Zhang *et al*., 2013; Wang *et al*., 2014; Celaleddin *et al*., 2016; Chen *et al*., 2016). In the past, most of the studies were conducted on ecological conditions and fertilizers to study the characteristics of grouting rate. Through cultivation measures, the grouting time can be affected and the final yield can be affected (Baduapraku *et al*., 2011; Lu *et al*., 2013; Wei *et al*., 2017). However, there are few studies on the filling rate characteristics of summer corn in different ripening periods in Heilonggang River basin. What are the differences in the grain filling process of summer maize during different ripening periods? It is easier to obtain high yields in breeding and planting hybrids of ripening stages, affecting different ripening periods. What are the key stages in the formation of maize grain weight? The above scientific questions have not yet been reported. The four corn hybrids selected in this study represent four different maturing maize hybrids in the Heilonggang river valley. Logistic models were used to analyze the characteristics of grain filling, providing theoretical basis for maize grain development regulation and selection of hybrids ripening period.

Materials and Methods

Materials

Four high-yield summer hybrids differing in maturities were used as experimental materials, the middle-early maturity hybrid Hengyu1182, early maturity hybrid Demeiya1, middle-late maturity hybrid Zhengdan958 and late maturity hybrid Nongda108.

Experiment Design

The experiment was conducted at the test station of Dryland Farming Institute, Hebei Academy of Agriculture and Forestry Sciences from June to October in 2017. The test station is located at 115° 42'45 "east longitude and 37° 53'27" north latitude with an elevation of 20m. The soil analysis indicated the soil type was clay loam, organic matter of 15.4 g kg^{-1}, cracked nitrogen of 81 mg kg^{-1}, available phosphorus of 179.7 mg kg^{-1}, respectively. This experiment used a randomized block design with three replicates. Each plot had an area of 40.2 m^2, including 10 rows with a row length of 6.7 m. Planting was performed according to an equal row spacing of 0.6 m and the planting spacing was 22.0 cm, the density of reserved seedings were 75 000 plants/hm^2, June 12 and October 1 were the sowing date and harvest date respectively, and daily average temperature is 15–35℃ during maize growth. According to the test requirements plant character investigation and yield traits investigation were performed during the growth period.

Treatments and Measurements

Determination of grain filling process: Before silking stage of maize, plants with simultaneous silking and strong uniform growth were selected for bagging and unified artificial pollination. Sampling work was performed from the 7^{th} d after silking and pollination once every 10 days until the seeds were mature. In each plot, 100 grains were obtained from the middle grain parts of 3 ears until the seeds mature, the dry weight and fresh weight of 100 grains were measured respectively.

The Determined Method of Dry Weight

The samples placed in the oven at 105℃ for 30 min, and then dried to a constant weight at 80℃, and the dried sample was weighed for analysis.

Water content and grain filling rate were calculated as follows:

Percentage of grain water (%) = (water amount/fresh weight) × 100%;

Grain filling rate (g/d)=[dry weight of 100 grains in later time(g)-dry weight of 100 grains in former time(g)]/sampling interval between the two times(d);

Analysis method of population grain filling characteristics as follows:

The grain filling process of the population was simulated by Logistic curve, and the equation was $W=A/(1+Be^{-kt})$. In the formula, W is the dry weight of grain per unit area, A is the maximum grain weight of theoretical unit area, B and K are the parameters to be determined, and t is the days after silking. For the first derivative of Logistic equation, we can get the equation of grain filling rate G, i.e. $G=AKBe^{-kt}/(1+Be^{-kt})^2$.

When applied, the following secondary parameters can also be derived for describing grain filling characteristics:

(1) The maximum grain filling rate G_{max} and the maximum filling time T_{max}, T_{max} = lnB/K, the T_{max} into the filling rate equation G_{max}, the initial accumulation potential R_0 = K;

(2) The average grain filling rate (G_{mean}) and active grain filling period (D) (G = AK/6, D= A / G);

(3) The grain filling process was divided into 3 periods, in the early, middle and late stages of grain filling process, the early grain filling stage (grain weight increasing stage) $T_1 = t_1$; the middle filling stage (grain weight quickening stage) $T_2 = t_2-t_1$; and the late filling stage (grain weight slowing stage) $T_3=t_3-t_2$, and average filling rates p_1,p_2 and p_3 of population grains in early, middle and late filling stage, which could be calculated according to formulas of $p_1=W_1/T_1$, $p_2=(W_2-W_1)/T_2$ and $p_3=(W_3-W_2)/T_3$, the dry weight of t_1, t_2 and t_3 corresponded to W_1, W_2 and W_3, respectively (Ke *et al.*, 2011; Shen *et al*., 2017).

Yield and Yield Components

At mature stage, 2 rows (not sampled) were harvested in each plot, and dried naturally after harvest. After threshing, the yield was measured (according to the standard water content of 14%). After harvest, 10 ears were randomly selected from each plot, and the row number, grain number per row and 1000 grain weight were measured.

Statistical Analysis

Microsoft Excel 2007 and SPSS ver.17.0 software were used for data processing and statistical analysis. CurveExpert 1.4 software was used to simulate the grain filling process after flowering. Significant test was carried out by LSD method; the significant level was 0.05, Sigmaplot 12.0 for mapping.

Results

Meteorological Conditions of Maize Growth Period

The daily mean temperature, average sunshine time and rainfall in June–October period of maize growth were shown in Fig. 1. The daily mean temperature in July was the highest, which was 27℃, and the lowest in October was 16.7℃; The average sunshine time in June was the highest, which was 8.3 h, and the lowest in August was 6.5 h; Rainfall was the largest in July, which was 141.2 mm, and rainfall was the lowest in September, which was 5.1 mm. Thus, during the period of maize growth, the rainfall and heat were the same period.

Yield and Yield Components of Maize Hybrids with Different Maturity Periods

As can be seen from Table 1, when the planting density was fixed, the yield of middle-early maturity hybrid Hengyu1182 was the highest, and the middle-late maturity hybrid Zhengdan958 was the second, and the early maturity hybrid Huamei1 was the lowest, compared with other hybrids, the yield difference of Hengyu1182 reached a significant level ($p<0.05$), and the yield of Hengyu1182 was increased by 8.6%, 18.7% and 21.0%, respectively, compared with Zhengdan958, Nongda108 and Demeiya1. There were no significant differences in grain rows per ear and grains per row between the 4 hybrids, and 1000 grain weight was the main source of yield difference among the 4 hybrids.

Comparison of Dry Weight and Fresh Weight of Different Maturity Hybrids at Grain Filling Stage

The grain weight of each maturity hybrid increased rapidly at grain filling stage (0–30 d), and slowed down after 50d (Fig. 2A). The early-maturing hybrid Demeiya1 was the highest in early filling stage (0–10 d), the second was Hengyu1182, and the late-maturing hybrid Nongda 108 was the lowest. This indicated that the early maturing hybrid had good prematurity, and the grain weight of early maturing hybrids was faster than other hybrids (0–10 d). At the filling stage (11–60 d), the 100 grain weight of Hengyu1182 was higher than other hybrids, the accumulation of dry weight of Demeiya1 was faster than Zhengdan958 and Nongda108 (0–30 d), and the accumulation rate was slower than Zhengdan958 and Nongda108 (30–60 d).

The fresh grain weight of 4 hybrids showed a trend that the rapid growth and slow decline occurs during the whole grain filling stage (Fig. 2B). Rapid growth was concentrated within 10–40 d after pollination, and slow decline was concentrated within 40–60 d after pollination. The 100 grain fresh weight of 4 hybrids reached the maximum value at 40 days after pollination, the value of Demeiya1, Hengyu1182, Zhengdan958 and Nongda108 were 42.8 g, 43.7 g, 45.2 g and 44.2 g, respectively.

Changes of Grain Filling Rate and Percentage of Grain Water in Different Maturity Maize Hybrids

The tendency of grain-filling rate of these 4 hybrids was expressed in single peak curve (Fig. 3A). The peak value of middle-early maturity hybrid Hengyu1182 was the highest, and the lowest was the early maturity hybrid Demaiya1, and the value were 1.12 and 0.99 g·100 $kernel^{-1}$, respectively. After the peak of grain-filling, the grain-filling rate of late maturity hybrid Nongda108 decreased the slowest, and fell the fastest in the early maturity hybrid Demaiya1.

As can be seen from Fig. 3B, the percentage of grain water of 4 hybrids decreased with the development process of kernel, which was consistent with the accumulation of dry matter in grains. The percentage of grain water of 4 hybrids can be divided into two periods: rapid decline and slow decline, and the former occurred at 10–30 d after pollination, and the latter occurred in 31–60 d.

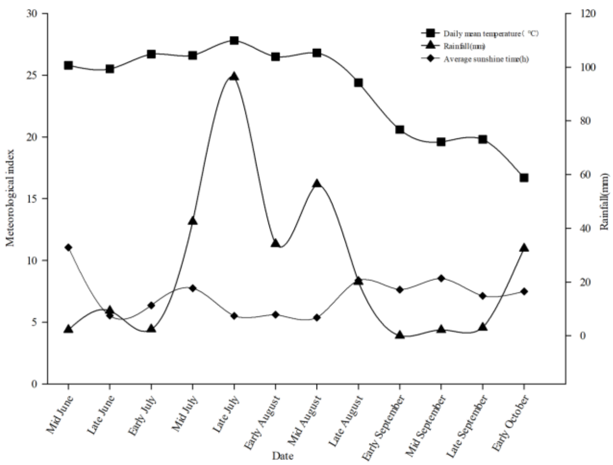

Fig. 1: changes of daily mean temperature, average sunshine time and rainfall during maize growing period

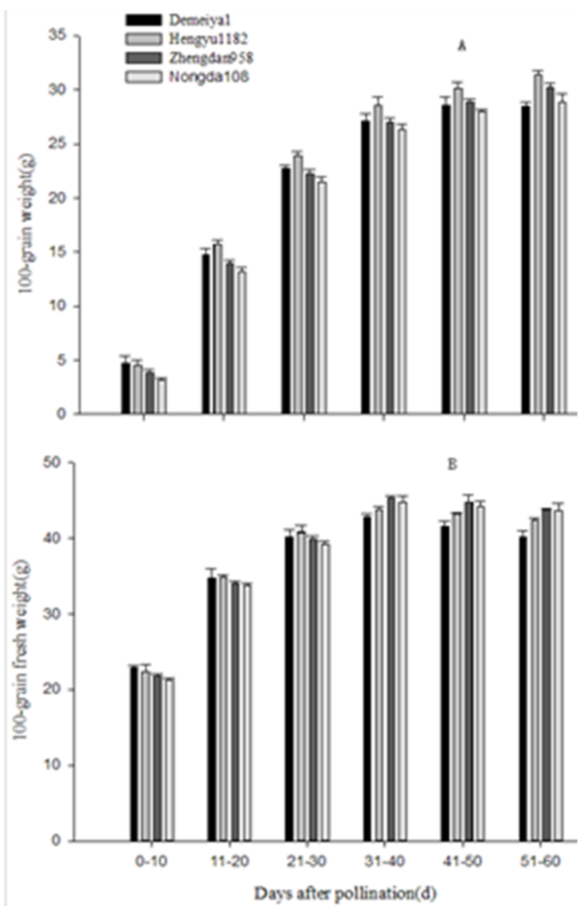

Fig. 2: Variations of grain weight and fresh weight in different maturity maize hybrids

The analysis of variance showed that the percentage of grain water of Nongda108 was significantly higher than other hybrids ($P<0.05$) after pollination at 60 d, which was 34.01%, and the lowest value was 25.70% for Hengyu1182.

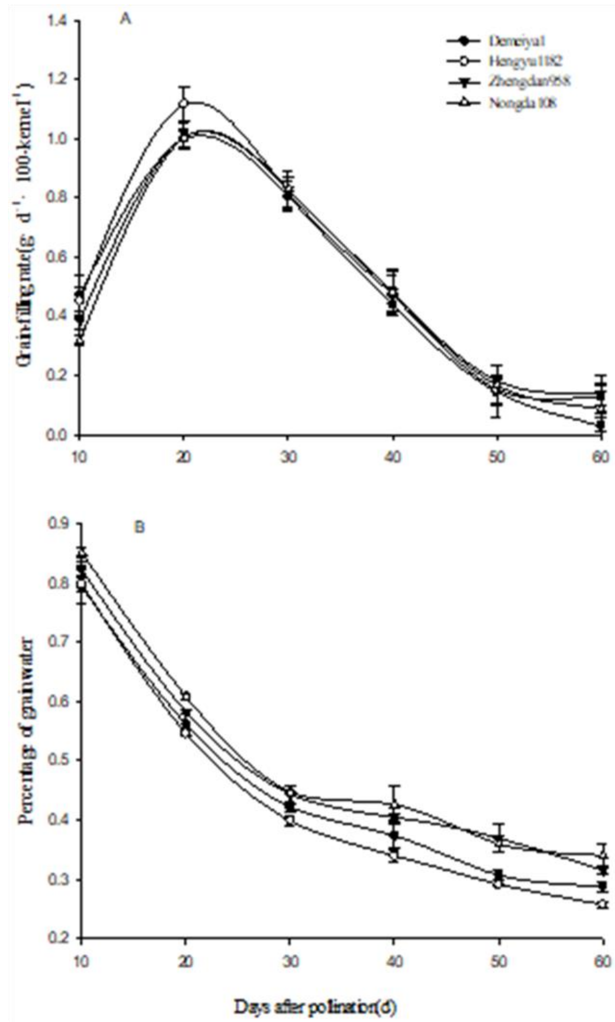

Fig. 3: Variations of grain filling rate and percentage of grain water in maize hybrids

Grain Filling Characteristic Parameters of Different Hybrids

In the days after pollination (t) as independent variables, every 10 d sample obtained 100 grain weight (Y) as the dependent variable, using the Logistic equation $Y=A/(1+Be^{-kt})$ on grain filling of different hybrids of process simulation, all hybrids of equations that determine the coefficient between 0.9944–0.9980, the results showed that the Logistic equation had higher fitting degree to grain filling process of each maize hybrid (Table 2). The initial grain-filling potential (R_0) of Demeiya1 and Hengyu1182 was higher than other hybrids, Nongda 108 reached the maximum rate of grain filling time (T_{max}), and Demeiya1 was the shortest; The maximum grain filling rate (G_{max}) and the average filling rate (G_{mean}) of Hengyu1182 were the highest, and Zhengdan958 was the smallest; the active filling period (D) of Zhengdan958 was the longest, and Nongda108 was the shortest.

Table 1: Yield and yield components of maize hybrids with different maturity periods

Hybrid	Grain rows per ear	Grains per row	1000-grain weight/g	Yield/(kg/hm^2)
Demeiya1	15.47a	33.67a	328.19c	11067.43c
Hengyu1182	16.14a	34.93a	366.25a	13386.24a
Zhengdan958	15.73a	33.89a	353.51b	12327.17b
Nongda108	15.93a	33.67a	350.33b	11275.36c

Note: Values sharing same letters differ non-significantly (P>0.05)

Table 2: The parameters of grain-filling characteristics in different hybrids

Hybrid	A	B	K	R^2	R_0	T_{max}(d)	G_{max}(g/d)	G_{mean}(g/d)	D(d)
Demeiya1	28.80	19.52	0.15	0.9980	0.15	20.30	1.05	0.70	41.02
Hengyu1182	30.78	19.68	0.15	0.9944	0.15	20.65	1.11	0.74	41.30
Zhengdan958	29.64	20.97	0.14	0.9950	0.14	21.75	1.04	0.69	42.33
Nongda108	28.41	26.27	0.14	0.9953	0.14	21.82	1.06	0.71	40.06

A: the maximum grain weight of theoretical unit area; B and K: the parameters to be determined; R^2: determination coefficient; R_0: initial grain-filling potential; T_{max}: the time reaching the maximum grain-filling rate; G_{max}: maximum grain-filling rate; G_{mean}: mean grain-filling rate; D: active grain-filling period

Table 3: The parameters characteristics of the three grain-filling phases in maize hybrids

grain-filling period	Parameters	Demeiya1	Hengyu1182	Zhengdan958	Nongda108
Early stage	t_1(d)	6.57	6.72	7.39	8.40
	T_1(d)	6.57	6.72	7.39	8.40
	W_1(g·100-kernel^{-1})	3.40	3.64	3.50	3.36
	P_1(g/d)	0.52	0.54	0.47	0.40
Middle stage	t_2(d)	24.56	24.97	26.21	25.99
	T_2(d)	17.99	18.25	18.83	17.59
	W_2(g·100-kernel^{-1})	18.75	20.04	19.30	18.49
	P_2(g/d)	0.85	0.90	0.84	0.86
Late stage	t_3(d)	51.70	52.50	54.60	52.51
	T_3(d)	27.13	27.52	28.39	26.52
	W_3(g·100-kernel^{-1})	28.51	30.47	29.35	28.12
	P_3(g/d)	0.36	0.38	0.35	0.36

t_1: days from silking to ending of early stage; t_2: days from silking to ending of middle stage; t_3: days from silking to ending of late stage; T_1: duration (days) of early stage；T_2: duration (days) of middle stage; T_3: duration (days) of late stage; W_1: increased grain weight of early stage; W_2: increased grain weight of middle stage; W_3: increased grain weight of late stage; P_1: mean grain-filling rate of early stage; P_2: mean grain-filling rate of middle stage; P_3: mean grain-filling rate of late stage

Comparison of Grain Filling Stage Characteristics of Different Hybrids

According to the Logistic curve, 4 kinds of mature maize hybrids were further analyzed. The whole process of grain-filling can be divided into early stage, middle stage and late stage (Table 3). The grain-filling duration of early stage (T_1), days from silking to ending of middle stage (t_2) and days from silking to ending of late stage (t_3) of late maturity hybrid Nongda108 and middle-late hybrid Zhengdan958 were higher than other two types in this trial, but mean grain-filling rate of early stage (P_1) was lower than other two types. The increased grain weight of every stage (W_1-W_3), and mean grain-filling rate of every stage (P_1-P_3) were higher than other three types. The days from silking to ending of middle stage (t_2), duration (days) of middle stage (T_2), days from silking to ending of late stage (t_3) and duration (days) of late stage (T_3) of Zhengdan958 were higher than other three types.

Discussion

As the core area of grain production in China, the Heilonggang River Valley has a special ecological environment and a “Double-Cropping” planting system (Zhu *et al.*, 1994). Therefore, in the practice of corn production, the growth period of the hybrid gradually shifts from the middle and late-maturing hybrids to the medium-early-maturing hybrids. While ensuring a steady increase in corn production, it also puts forward higher requirements for achieving maize grain harvesting (Jia *et al*., 2017; Li *et al*., 2017). With the extension of growth period, the utilization time of light will also extend, and ultimately had higher yield. However, for Heilonggang river valley, after summer corn is matured, there will be a single season of wheat. Late-maturing hybrids will often lose their yield because they cannot mature normally, and the middle-early maturing hybrids are more suitable for this area. This study shows that the four maize hybrids differing in maturities, yield of middle-early maturing hybrid was significantly higher than that of other hybrids ($P<0.05$), yield of middle-late maturing hybrid Zhengdan958 was significantly higher than that of early-maturing hybrids Demaiya1 and late-maturing hybrids Nongda108 ($P<0.05$). There is no significant difference between Demaiya1 and Nongda108 ($P>0.05$). In Heilonggang summer maize planting area, due to the lack of light and heat resources in the late growth period of maize, in order to obtain high yield, the production of middle-early maturing hybrids has always dominated, and local farmers are also increasingly inclined to plant hybrids with early maturity and high yield. The best growth period of corn hybrids in the Heilonggang valley is about 100 days. Breeders should select the early maturing materials to breed a short growing hybrid, and in production, more middle-early hybrids should be selected. It can not only avoid grain mildew caused by excessive moisture at harvesting, but also accelerate grain dehydration for mechanized harvest (Wang *et al*., 2014; Shao *et al*., 2016).

Maize yield is determined by ear number per unit area, grain number per ear and 1000 grain weight, when the two first items were fixed, 1000 grain weight has decisive significance to yield (Eta-Ndu and Openshaw, 1992; Paponov *et al*., 2005; Borrás *et al*., 2009). This study showed that, in the same cultivation conditions, the yield of middle-early maturity hybrid Hengyu1182 was significantly higher than other hybrids, 1000 grain weight was the main reason for the yield difference between the four types hybrids. The difference of grain weight between different maturity period maize hybrids is very large, but the difference of grain weight is mainly caused by different filling process. There are different views on the effect of grain filling process on grain weight and yield, mainly concentrated on the two aspects in grain filling rate and grain filling time. One view is that the difference between grain yield is mainly formed after pollination 30d, and the main determinant factor is the length of grain filling (Edmore *et al*., 2013; Qian *et al*., 2017). Another view is that grain filling rate is the main limiting factor for yield increase (Ottaviano and Camussi, 1981; Johnson and Tanner, 1972; Gasura and Setimela, 2014). The more easily accepted view is that the grain weight is determined by both the grain filling time and the grain filling rate (Johnson and Tanner, 1972). The results showed that the final yield of Hengyu1182 was the highest, while analyze the grain-filling parameters, the average grain-filling rate and the maximum grain-filling rate were higher than the other three hybrids, indicating that the increase of grain weight was mainly due to the increase of grain filling-rate. Therefore, to increase corn yield, it is possible to increase the filling rate at each filling period. In breeding, due to genetic control of grain filling rate, hybrids with high filling rates can be selected through breeding methods. In production, by increasing the supply of nitrogen fertilizer at 30d after flowering, timely filling of grain filling rate is conducive to improving the photosynthetic physiological activity of plants and further increasing the yield of maize (Huang *et al*., 2007). Through this study, we believe that the middle-early maturity maize hybrids in Heilonggang river valley have more market prospects.

Conclusion

This article mainly studied the differences in grain filling characteristics of maize hybrids with different maturity. Among the 4 different maturing maize hybrids, the grain yield of middle-early maturing hybrid Hengyu1182 was the highest, which was significantly higher than that of the other three hybrids. The reason for the analysis is that the medium-early-maturing hybrid Hengyu1182 has higher average filling rate and maximum filling rate than other hybrids. Breeders should pay attention to the selection of materials with fast filling rates when choosing materials, and middle-early maturity hybrids will have broad prospects for promotion in the Heilonggang area.

Acknowledgments

This work was funded by the National Natural Science Foundation of China (31601386); Shandong Key Research and Development Plan (Public Welfare Special Project, 201723), the National Key Research and Development Program of China (2017YFD0701203), the Special Fund for National System (Maize) of Modern Industrial Technology (nycytx-02), the Science and Technology Support Program of Hebei Province (16226323D-X), and the Youth Science Fund of Hebei Academy of Agriculture and Forestry Sciences (A2015040101).

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(Received 20 March 2018; Accepted 10 April 2018)