The Growth Analysis in the Wheat Filling Process of the Two Hybrids and Their Parents Based on Richards Equation

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Abstract: Using Origin software, the grain filling process of hybrid wheats 1-12 and 8-1-54 and their parents was fitted by Richards equation $W=A/(1+Be^{-kt})^{1/N}$ on computer in order to study the characteristics of grain filling in hybrids wheat. The active grain growth period of hybrid wheats 1-12 and 8-1-54 were longer than that of their parents respectively, and their final grain weight was higher than that of their parents respectively. These results suggest that hybrids 1-12 and 8-1-54 have the higher capacity of graining filling than their parents and that may be associated with longer RGFP and higher maximum grain-filling rate. It was also found that Richards equation was more suitable for fitting the grain filling process of wheat than Logistic equation.

Key words: Hybrid wheat; Richards equation; Parent plants; Grain-filling

1 Introduction:

The grain filling period is one of the most important stages in the life of wheat． During this period， wheat grains are filled and the final yield forms[1-2]． Researches on this stage have an important significance in revealing the characteristics of grain quality and growth． A large number of reports have been existed on the filling process and filling characteristics of wheat grain[2-4]． Zhang[5] and Ren et a1． [6]analyzed the grain filling traits using the third degree polynomial． Gu et a1． [7]analyzed the barly grain filling traits using Logistic equation． However． the third degree polynomial and Logistic equation are lack of enough plasticity， and difficult to give biological meanings of model parameters． Zhu et a1． [8] and Yang et a1． [9] once reported that it was much better to use Richards equation to simulate the rice grain filling process than Logistic equation[10]． Application of this equation to wheat grain filling process has not been reported till now．

Using the most available equation for fitting growth analysis (Richards equation) and a set of subsidiary parameters derived from Richards equation[11-13]， we propose to simulate and analyze the grain filling data of hybrid wheat 1-12 and its parents(Jing411 and Xiaoyan54)，8-1-54 and its parents(8602 and Xiaoyan54) ，to compare their filling traits.

2 Material and methods:

2.1 Plant material

Winter wheat was grown at a farm in Beijing in 2012-2013. The sowing time of wheat seeds was 2 October, 2012. During this time to ensure adequate supply of nutrients and water, so as to avoid the occurrence of stress. Measurements began in May 10th at the stages of anthesis and end in June 13th after flowering. During this period, the weather in Beijing is typical of the spring weather, the average temperature of 19-23 degrees Celsius, the average daily light intensity(PPFD) of about 1400 μ mol m^{-2} s^{--1} at noon. There are varieties of Jing411, Xiaoyan 54, 1-128602, 8-1-54. 1-12 is the hybrid progeny of Jing 411 and Xiaoyan 54, So Jing411, Xiaoyan 54 and 1-12 will be known as the Jing 411 series. 8-1-54 is the hybrid progeny of 8602 and Xiaoyan 54, so 8602, Xiaoyan 54 and 8-1-54 will be called the 8602 series.

Sampling and harvesting

From anthesis to maturity stage, twenty labeled wheat shikes were selected to sampled every 3 days. The samples were divided into two groups (10 spkies each). wheat kernels taken out were dried at 75 degrees for 72 hours to the constant weight and then weighed.

Using the Origin software， the grain tilling data is fitted by the Richards equation， with the grain weight W as the dependent variable，days after anthesis(t)as the independent variable．

$$W=A/(1+Be^{-kt})^{1/N} \qquad (1)$$

W--the grain weight (mg),

A-- the final grain weight (mg),

t --the time after anthesis (day),

B, K, and N -- the coefficients determined by the regression.

T1 was 5% of W and t2 was 95% of W. So the active grain-filling period was defined as the period of t1 to t2. The average rate was calculated by the rate from t1to t2.

And grain-filling rate (G) was calculated as the derivative of Equation (1)：

$$G=AKBe^{-kt}/N\ (1+Be^{-kt})^{(N+1)/N} \qquad (2)$$

Where G is the growth amount per unit time (g/1000 grains d^{-1})

For further analysis, the following subsidiary parameters can be derived from Equation (2) to describe the filling traits.

The date of the maximum grain filling rate: Tmax.G= (lnB-lnN) /k

The growth quantity in t he maximum grain filling rate: Wmax.G=A(N+1)-1/N

The maximum grain filling rate: Gmax=(kWmax.G/N)[1-(Wmax.G/A)N]

Filling starting potential: R0=k/N

The active grain-filling phase (about 90% of total growth quantity): D=2 (N+2) /k

The ratio of the growth quantity in the maximum grain-filling rate and the final grain weight: I=Wmax.G/A

2. Results

2.1 Grain filling process and rate

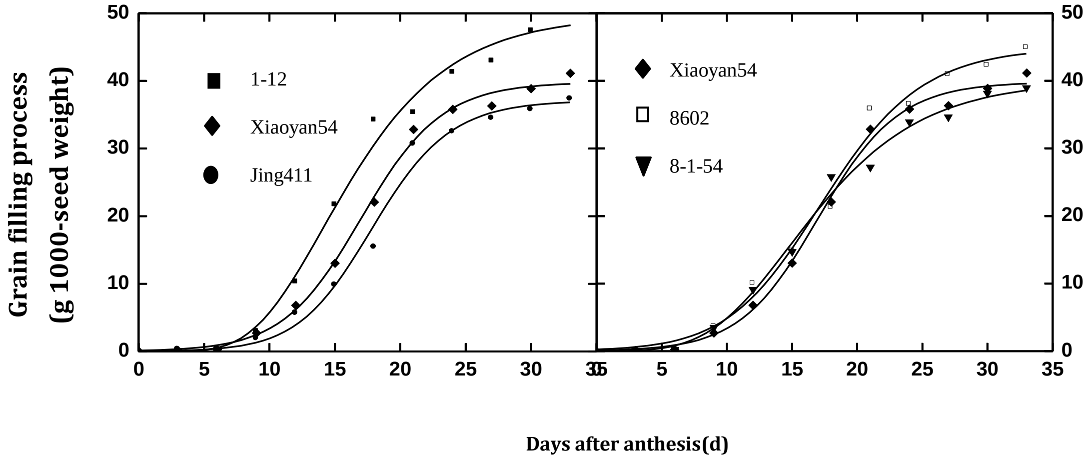

Figure 1. The grain filling process fitted by Richards equation. Each point represents the mean ±SE of the 1000-seed dry weight, n=3.

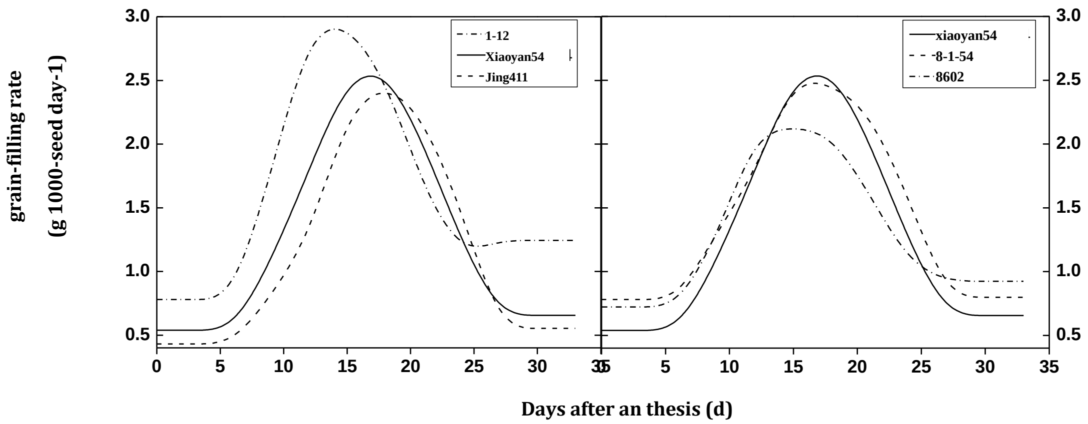

Figure 2. The grain filling rate of fitting Richards euqation.

Figure 1 and Figure 2 show the grouting process and grain filling rate of the 5 wheat varieties. In all varieties, the delay and exponential phase can be clearly seen. 31 days of measuring time is sufficient to reveal the rapid filling process. The final grain weight of 1-12 was significantly higher than that of other cultivars. 1-12 into the rapid filling period and dry matter accumulation period was faster and earlier than their parents. The final grain weight of 8-1-54 was significantly higher than that of the parents. Figure 2 shows the curve of the grain filling rate of the five varieties of wheat fitted according to the Richards (1959) equation[13]. From these data, the grain filling rate and the time to reach the maximum filling rate (Tmax) are obtained.In all varieties, the rapid grain filling began at the same days (5 days) after anthesis and ended at the same days (28 days) after anthesis except 1-12 (25 days). 1-12 had the highest maximum grain-filling rate peaking at around 3.0 g 1000-seed day^{-1} that was comparable to its parents jing411 and xiaoyan54,.and the maximum grain filling period (MRGFP) of 1-12 occurred earliest (13 days after anthesis) in all varieties, but the grain filling period was shortened (5-25 days). In all varieties, the lowest overall rate of grain filling is 8602 (2.0 g 1000-seed day^{-1}) and this variety showed a longer grain-filling period than its parents.

These results suggest that hybrids 1-12 and 8-1-54 have the higher capacity of graining filling than their parents and that may be associated with longer RGFP and higher maximum grain-filling rate.

2. 2 The grain filling model in different varieties and different grain positions

From results of the determination coefficient (R^2) (Table1), the kernel filling processes in 5 cultivars are better fitting by Richards equation. Hybrid wheat 1-12 and 8-1-54 have a high grain weight,with the final weight about 46.7g and 44.7g per 1000grains,apparently higher than their parents.

From the initial growth potential Ro of the five types of varieties, the lowest initial growth potential (R0) is Xiaoyan54 0.184, followed by jing411 to 0.290,8-1-54 to 0.322, the higher is 8602 0.839, the highest is 1-12 0.932. So the starting potential of the varieties are: 1-12>jing411 and xiaoyan54, but 8-1-54> Xiaoyan54, and <8602. The results showed that the growth potential of 1-12 is greater than its parents. Seed starting potential reflects its growth potential in ovary, Ro value is larger, the endosperm cell division cycle is shorter, split faster and grain filling start earlier; Conversely, Ro value is smaller, the grain filling starts later; If R0 Value is too small, the endosperm cells can not develop normally, grain filling process tends to stop.

Table 1. Parameters of different Grain Positions in grain filling period

Varieties	A	B	K	N	R_0	T_{max}	G_{max}	$W_{max.G}$	I	D	R^2
1-12	46.7	1.0000	0.215	0.201	0.932	7.498	3.987	18.79	0.4020	20.47	0.996
Xiaoyan54	36.7	2.852×10^{17}	2.085	11.152	0.184	13.388	3.301	29.37	0.7994	12.62	0.995
Jing411	34.7	31396.8	0.8468	2.91886	0.290	10.468	3.479	21.75	0.6263	11.62	0.987
8-1-54	44.8	19.321	0.251	0.779	0.322	12.787	3.502	21.36	0.4774	22.14	0.994
8602	40.6	1.007	0.2	0.168	0.839	9.588	2.784	16.09	0.3968	21.68	0.997

B、K、N：Parameters of the equation; A： The maximum grain weight; R_0： Initial growth potential ; Tmax: the time reaching the maximum grain-filling rate; Gmax：The maximum grain-filling rate; $W_{max.G}$: the growth quantity in the maximum grain filling rate; D: The active grain-filling phase (about 90% of total growth quantity); I: the ratio of the growth quantity in the maximum grain-filling rate and the final grain weight

The time reaching the maximum grain-filling rate (T_{max}) of the 1-12 is 7.498d, and that of 8-1-54 is 12. 787d.The longest of T_{max} is Xiaoyan54 13.388d. There is obvious regularity: the larger of the initial growth potential Ro of the variety, the shorter of the Tmax .

The maximum grain filling rate (G_{max}) of hybrid wheat 1-12 and 8-1-54 are also higher than their parents.The ratio of the growth quantity in the maximum grain-filling rate and the final grain weight (I): Xiaoyan54 reached 79.94%, followed by jing411 is 62.63%, the second is 8-1-54 47.74%, 1-12 is 40.20% and 8602 is 39.68%. To sum up, the maximum grain filling time of 1-12 appeared earlier, the grain filling in active growth is longer. The grain has just completed the final volume of 40% in maximum graining-filling rate, which showed the later grain filling grain weight gain still can continue to increase if the conditions permit. The maximum filling rate of Xiaoyan54 appeared later, the active growth period is shorter, and when it reached the maximum rate of grain growth, it has been completed around the final growth of 80%, indicating grain growth is significantly restricted in the later period; To other three varieties, growth characteristics was between the varieties of Jing411 and xiaoyan54. These results suggests that it has heterobeltiosis.

2.3 Division of grain filling type

Richards growth curves are a group of curves determined by N value. From the filling rate curve (Figure1 and Table1) can be seen when O<N<l, the initial growth potential Ro is higher and rate curve is left, the grain is belong to the strong grains. When N＞l, rate curve is right and Ro is lower, the grain is belongs to the inferior grains. When N=l, the Richards equation is equal to the Logistic equation, So Richards curve can be used to simulate grain filling types.

The N values in the hybrid wheat and 8602 are <l, and the growth rate curves go left. These mean that the kernels grow quickly in the early filling stage, and slow down in the middle and late filling stages. The N value of the male parent (8602) of 8-1-54 was smaller than that in the hybrid, while the growth rate skewed left much more, resulting in a slower growth in the middle and late filling stages(Table1, Fig2)

The N values in jing411 and xiaoyan54 are both larger than 1, and the growth rate curves skewed right, resulting in longer duration to Gmax, Tmax values were 10.468 d and 13.388 d respectively, suggesting slower growth in the early filling stage and fast growth in the middle filling stage (Table 1, Fig 2).

3. Discussion

Logistic equation and Richards equation can simulate the grain filling process of wheat[14]. There are 3 fitting parameters in logistic equation, but there has an additional parameter N in Richards equation [13, 15]. So the Richards equation has a larger degree of freedom and more flexibility, and in the theory, it should be more fitting than Logistic equation. The present results showed that Richards equation was fitting well with the filling process for 5 cultivars, resulting in larger determined coefficient (R^2). equation. Furthermore, more information can be achieved according to the value of N. As a result Richards equation is better than Logistic equation in describing the kernel weight increment process, and it could reveal fully the differences in the filling process between varieties.

The results proved in the middle and late stages of graining filling, photosynthetic product and storage capacity of the hybrids of 1-12 and 8-1-54 are adequate. Because their source and sink relationship is coordinated with each other, so they can form a large and full grain; On the contrary, the storage capacity of jing411 and other parents cultivars is sufficient, but supply of photosynthetic products is not insufficient, so grains are big and not full, as the "source" limited type variety. So how to increase the filling duration and fully enhance its production potential to get a higher yield, are the main topic to be done next.

The superior grains varieties were the “storage capacity “limited, so to increase 1000 grain weight, we should pay attention to the promotion of endosperm cell division and expansion. But to the "source" limited variety, we should to improve the nutrition supply to improve grain weight.

Although the results of using polynomial regression and Logistic equation to simulate the process of grain filling are not as good as results of Richards equation, they can be liberalized, and have more mature test equation. They are widely used in agricultural scientific research because of the use of Excel software in computer. Regression equation of Richards equation belongs to nonlinear, cannot use the Exel software to finish, and need to determine the initial values of parameters after using SAS or Matlab software program by Levenberg - Marquardt algorithm and need to establish Richards equation after to select of stable and the minimum Q value. The key point of the whole process is the choice of initial parameter values; but the initial parameters can be determined by crop characteristics and professional knowledge or reference parameters, which is main reason that the Richards equation is not used as the other two equations widely.

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