Journal of Cereal Science 73 (2017) 116–121

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

Research note

Characteristics of starch synthesis and grain filling of common buckwheat

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ARTICLE INFO

Article history:
Received 24 May 2016
Received in revised form
18 December 2016
Accepted 20 December 2016
Available online 22 December 2016

Keywords:
Common buckwheat
Grain filling
SSS activity
ADPGP activity
Richards equation

ABSTRACT

The common buckwheat 'cv. Fengtian 1' (FT1), 'cv. Yuqiao 4' (YQ4), 'cv. Dingtian 2 (DT2)', and 'cv. Tongliao (TL)' were selected to investigate the characteristics of starch synthesis and grain filling. The chlorophyll and chlorophyll *a*/*b* contents of leaves in the third stem showed a steady downward trend with the growth of common buckwheat. Whereas, FT1, YQ4 and DT2 showed higher chlorophyll content than that of TL at 7d and 14d. The activity of soluble starch synthase(SSS) and adenosine diphosphate glucose pyrophosphorylase (ADPGP) in the four tested varieties showed a rapid upward trend until 14 days after heading but then rapidly decreased until 21 days after heading. The average adenosine diphosphate glucose pyrophosphorylase activities of FT1, YQ4 and DT2 were higher than TL, while the average soluble starch synthase activities were similar among the four tested varieties. Consistently, the four tested varieties showed rapid accumulation of starch, amylose, and amylopectin during the prefilling stage, but no difference of starch content was found at maturity. The filling process of the four common buckwheat varieties exhibited an "S" curve. The Richards equation was utilized to evaluate the grain-filling process of common buckwheat. YQ4 showed the largest values of initial growth power (R_0). The time reaching the maximum grain-filling rate ($t_{max.G}$) of FT1 was the longest, and the maximum grain-filling rate (G_{max}) of DT2 was the fastest.

1. Introduction

The grain-filling period plays an important role in crop growth as this period is very closely related to the crop yield. Previous research on rice indicated that the grain weight of rice depends mainly on the grain-filling characteristics after flowering and insemination. Previous reports have also confirmed the different grain-filling types and grain-filling characteristics of rice, modeled the grain-filling process with Richards's equation, and highlighted some control measures for the rice grain-filling process (Yang et al., 2001; Nakamura and Yuki., 1992; Tomlinson and Denyer, 2003; Mizuno et al., 1992; Fu et al., 2009). Leaf cutting, thinning, and applying nitrogen fertilizer or other treatment to rice in the heading stage can regulate source-sink relations or the nutrition level in plants at the early filling stage, increase or decrease enzyme activity, especially in the inferior grains, and improve the seed setting rate and grain weight (Yang et al., 2003). The grain filling period is the critical period of wheat to form grain weight and yield (Nass and Reiser, 1975; Keeling et al., 1993; Gelanga et al., 2000; Yang et al., 2011; Mingrong et al., 2000; Wang and Wang., 2004). The grain filling to maturity period is the critical period of maize to form yield, and filling characteristics are a predominant influence of yield formation at the late growth stage of maize (Doehlert et al., 1988; Li et al., 2010; Xu et al., 2013; Wang et al., 2006; Zhang et al., 2007; Shen et al., 2005).

The multispecies of *Fagopyrum* can be classified into two types: common buckwheat (*Fagopyrum esculentum*) and tartary buckwheat (*Fagopyrum tataricum*) (Lin, 1994). Lin (1994) concluded that grain weight is determined by the grain-filling process, which is similar to other grain crops, such as rice. At present, research is lacking on the grain-filling process of buckwheat, which seriously affects awareness on the yield and effective regulation of buckwheat. The current experiment used four common buckwheat varieties with different yields to study the differences in physiological and biochemical characteristics among common buckwheat

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http://dx.doi.org/10.1016/j.jcs.2016.12.008

varieties during grain filling. The results will serve as a theoretical basis for high-yield cultivation of common buckwheat.

2. Materials and methods

2.1. Plant materials and growth

The common buckwheat 'cv. Fengtian 1' (FT1), 'cv. Yuqiao 4' (YQ4), 'cv. Dingtian 2 (DT2)', and 'cv. Tongliao (TL)' used in this experiment were provided by the Buckwheat Industry Technical Research Center of Guizhou Normal University. Among national common buckwheat varieties in China, FT1 had a high yield, YQ4 and DT2 had a middle yield and TL had a low yield, during the two growing seasons in 2013 and 2014.

FT1 and YQ4 showed higher plant height than the other two common buckwheat varieties, whereas TL exhibited the lowest plant height (Table 1). The stem branch number and stem node number showed no significant difference among different common buckwheat varieties. FT1 produced the most grains per plant and had the highest grain weight per plant. FT1 exhibited the highest yield at maturity; its yield was 27.3% higher than that of TL, which had the lowest yield. FT1 had a high yield, YQ4 and DT2 had a middle yield, and TL had a low yield, which were similar to the data from two growing seasons (late March in 2013 and middle October in 2014).

The experiment was conducted at the Experiment Station of the Research Center of Buckwheat Industry Technology in Guizhou Province, China (908 m, 26°35′ N, 106°52′ E). The soil was yellow loam that contained 17.6 g kg^{-1} organic matter, 1.06 g kg^{-1} total nitrogen, 111 mg kg^{-1} alkaline nitrogen, 8.0 mg kg^{-1} valid phosphorus, and 121 mg kg^{-1} valid potassium; which was tested in 2013. The experiment involved a randomized block design with three replications. Common buckwheat seeds were sown on March 28, 2015. The area for each test plot was 2 m × 10 m, and the spacing for each row was 33 cm. Before sowing, 30 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 30 kg K_2O ha^{-1} were applied as base fertilizer. About 1200 plants for each plot with uniform growth were selected and tagged before flowering. About 10–15 tagged plants from each plot were sampled every 7 days from 7 days after flowering (7 days after heading) to maturation.

2.2. Sample preparation

Half-sampled grains of every period were frozen in liquid nitrogen for 1 min and then stored at −80 °C for enzymatic measurement. The other half of grains dried to a constant weight at 60 °C for 72 h, dehulled, weighed, and used to analyze grain growth and determine the starch content. Leaves in the third stem of common buckwheat were sampled to determine the chlorophyll, chlorophyll *a*/*b*, soluble carbohydrate, and soluble protein contents. Plant height, number of stem branches, number of stem nodes, grain number per plant, grain weight per plant, and hundred-seed weight were determined from 10 plants that were randomly sampled from each plot at maturity. The yield of each plot was determined at maturity.

2.3. Determination

The chlorophyll, chlorophyll *a*/*b*, soluble carbohydrate, and soluble protein contents in leaves were analyzed using the method of Zou (1995).

The processes of grain filling in the grains were fitted by Richards' (1959) growth equation as described by Zhu et al., 1998 and Gu et al. (2001).

The days after flowering (t) was set as the independent variable, and the seed weight (W) was set as the dependent variable as follows:

$$W = A\Big/\left(1 + Be^{-Kt}\right)^{1/N}$$

W represents the grain weight of buckwheat during grain filling, A represents the final grain weight at harvest, B represents the initial value of parameter, K represents the constant growth rate, N represents the shape parameter, t represents the time after flowering (the flowering day was marked as 0 d), and R^2 represents the compatibility.

$$G = (KW/N)\left[1 - (W/A)^N\right]$$

$$G = (K/N)\left[1 - (W/A)^N\right]$$

$$R_0 = K/N$$

G represents the growth in unit time during grain filling, R represents the relative growth rate, and R_0 represents the initial growth power.

$$T_{max.G} = (1nB - \ln N)/K$$

$$W_{max.G} = A(N+1)^{-1/N}$$

$$V_{max} = (KW_{max.G}/N)\left[1 - (KW_{max.G}/A)^N\right]$$

$$t_1 = -\ln\left[\left(N^2 + 3N + N\sqrt{N^2 + 6N + 5}\Big/2B\right)\right]\Big/K$$

$$t_2 = -\ln\left[\left(N^2 + 3N - N\sqrt{N^2 + 6N + 5}\Big/2B\right)\right]\Big/K$$

$T_{max.G}$ represents the time with maximum grain-filling rate, $W_{max.\ G}$ represents the growth at the day with the maximum grain-filling rate, V_{max} represents the maximum grain-filling rate, t_1 represents the starting day of the maximum grain-filling period, and t_2 represents the ending day of the maximum grain-filling period.

The method of Nakamura and Yuki, (1992) was used to prepare the enzyme extracts. In brief, dehulled and frozen grains were

Table 1
Major agronomic traits and yield of common buckwheat.

Variety	Plant height(cm)	Stem branch number(individual)	Stem node number (individual)	Grain number per plant(grain)	Grain weight per plant(g)	Yield(kg/hm^2)
FT1	57.6a	3.3a	7.0a	45.00a	1.75a	1263.00a
YQ4	58.0a	3.0a	6.0a	40.67b	1.56b	1189.03b
DT2	55.8b	3.0a	6.0a	39.33b	1.30c	1092.93c
TL	51.5c	2.6a	6.3a	33.67c	0.94d	991.90d

Different small letters indicate the significant difference ($P \leq 0.05$) among the same multispecies analyzed by LSD using SPSS 17.0.