Field Crops Research 149 (2013) 177–186

Contents lists available at SciVerse ScienceDirect

Field Crops Research

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

Maize kernel growth at different floret positions of the ear

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ARTICLE INFO

Article history:
Received 28 February 2013
Received in revised form 23 April 2013
Accepted 27 April 2013

Keywords:
Maize
Kernel weight variation
Floret position
Kernel growth rate
Grain filling
Yield

ABSTRACT

The variation of individual kernel weight can have a large impact on final yield of maize (*Zea mays* L.). The goal of this research was to investigate the variation of maize kernel dry weight (KW) along the rachis of the ear and to determine the effect of kernel growth parameters on this variation. Field experiments were conducted for three years using two hybrids with contrasting plant densities. The fresh and dry weights of each kernel from one row of the ear were measured. Kernel growth at the basal, upper and apical sections of the ear was compared with that at the lower third section. The KW distribution in one row was the highest for the lower third section, followed by the basal and upper sections and the lowest for the apical section. The relative decrease in final KW of the other sections relative to the lower third section was determined by both the decrease in rate and duration of linear grain-filling for the normal density treatments, and was only determined by the decrease in growth rate for the low density treatments. The distribution of kernel water mass in one row showed the same trend as KW. However, the developments of kernel moisture content among sections were quite similar. The relative change in final KW of the other sections relative to the lower third section was closely correlated with the relative change in kernel maximum water mass (R^2 = 0.99). This study reflects the substantial difference in KW along the rachis of the ear and indicates that the mechanism of individual kernel growth should be integrated into maize simulation models in order to predict yield more accurately.

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world. Although maize yield is mainly determined by the kernel number per unit land area (Otegui, 1995; Chapman and Edmeades, 1999), large deviations in crop yield estimation can occur because of the variation in the weight of individual kernels (Borrás et al., 2004; Borrás and Gambín, 2010). A large variation in kernel dry weight (KW) for different hybrids and environments has been reported (Saini and Westgate, 1999; Borrás et al., 2004). However, the information of kernel variation among the position on the ear and the physiological mechanisms controlling the variation are still lacking.

The individual KW accumulation is controlled by the kernel growth rate and the duration of linear grain-filling (Borrás and Gambín, 2010). Many studies have been conducted on kernel growth of cereal crops, including maize (Borrás et al., 2003; Echarte et al., 2006; Sala et al., 2007a), wheat (*Triticum aestivum* L.) (Slafer and Savin, 1994; Acreche and Slafer, 2009) and sorghum (*Sorghum bicolor* (L.) Moench) (Gambín and Borrás, 2005). It has been suggested that the assimilate availability per kernel during the early growth stage determines its potential sink capacity and is closely related to the kernel growth rate during the linear grain-filling period (Capitanio et al., 1983; Andrade et al., 1999; Gambín et al., 2006; Borrás and Gambín, 2010). The duration of linear grain-filling is related to the environmental conditions during the grain-filling stage for a given hybrid. For example, drought (Barlow et al., 1980; Brooks et al., 1982; Westgate, 1994), severe pathogen infestations (Pepler et al., 2006), or defoliations (Egharevba et al., 1976; Echarte et al., 2006; Sala et al., 2007a) can significantly shorten the filling duration. On the other hand, an increase in assimilate supply does not influence the duration of grain-filling if the assimilate supply is non-limiting (Borrás et al., 2003).

The water mass of a kernel rapidly increases during the early stage of kernel growth (Saini and Westgate, 1999) and obtains its maximum value during the middle of the grain-filling period (Westgate and Boyer, 1986; Borrás et al., 2003; Gambín et al., 2007a). The maximum water mass of a kernel has been suggested to be a good indicator of potential kernel sink capacity (Borrás and Westgate, 2006). It was correlated with kernel growth rate and

Abbreviation: KW, kernel dry weight.

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http://dx.doi.org/10.1016/j.fcr.2013.04.028

Table 1
Sowing, emergence and silking dates of each treatment.

Year	Hybrid	Plant density (plant m^{-2})	Sowing date	Emergence date	Silking date
2008	ND108	2.8	24 May	1 June	31 July
	ND108	5.6	24 May	1 June	31 July
2009	ND108	5.6	8 May	15 May	19 July
	ZD958	2.8	8 May	15 May	15 July
	ZD958	5.6	8 May	15 May	17 July
2010	ND108	2.8	13 May	21 May	19 July
	ND108	5.6	13 May	21 May	20 July
	ZD958	2.8	13 May	21 May	14 July
	ZD958	5.6	13 May	21 May	18 July

final KW for a wide range of genotypes and environments (Millet and Pinthus, 1984; Schnyder and Baum, 1992; Saini and Westgate, 1999; Borrás et al., 2003). After maximum water mass, the water in a kernel is gradually replaced by dry matter deposition until the physiological maturity has been reached (Egli and TeKrony, 1997; Saini and Westgate, 1999; Sala et al., 2007b). The moisture content declines throughout the grain-filling period (Westgate and Boyer, 1986) and it has a close relationship with percentage of dry matter accumulation over a wide range of genotypes and environments (Borrás et al., 2003). The moisture content has been used as a 'benchmark' for estimating kernel development for different environmental conditions (Calderini et al., 2000; Calviño et al., 2002).

Some studies have found that kernel growth rate and duration of linear grain-filling vary for different floret positions on the rachis because of the internal competition for assimilate and, therefore, results in differences in final KW (Tollenaar and Daynard, 1978a, 1978b; Munier-Jolain et al., 1994; Andrade and Ferreiro, 1996; Gambín and Borrás, 2005). For maize, the top kernels on the rachis initiate their growth 4–5 days later than the basal ones and have a higher possibility of abortion prior to the onset of grain-filling (Tollenaar and Daynard, 1978a). The later fertilized kernels have a lower kernel growth rate and shorter duration of linear grain-filling which results in a lower final KW (Tollenaar and Daynard, 1978a, 1978b; Hanft et al., 1986; Muchow, 1990). Detailed information about the variation of KW with its growth parameters (kernel growth rate, duration of linear grain-filling), and kernel water development along the rachis is scarce. A more detailed understanding of the underlying physiological mechanisms that control the variation in KW is needed in order to be able to improve mechanistic crop models for a more accurate yield simulation (Borrás and Gambín, 2010).

The objectives of this research were (i) to investigate the difference in KW along the rachis of the ear; (ii) to determine the impact of kernel growth parameters on final KW, and (iii) to evaluate the dynamics of kernel water for different sections of the ear and to determine the relation with KW.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted in 2008, 2009 and 2010 at the Shangzhuang experimental farm (40°08′ N, 116°10′ E) of China Agricultural University. The soil was a sandy clay loam (Aquic Cambisol). Two maize hybrids, ND108 and ZD958 that have the largest planting acreage in China since 2000 were used in this study and two different plant densities were evaluated. Row and plant spacing was 0.6 m for the low density treatment (2.8 plants m^{-2}), while plant spacing was 0.3 m and row spacing was 0.6 m for the normal density treatment (5.6 plants m^{-2}). The normal density represents the plant density commonly used by local farmers. In 2008, ND108 was planted at both a low and normal densities. In 2009, both hybrids were used for comparison: using low and normal densities for hybrid ZD958 and only normal density for hybrid ND108. In 2010, both hybrids were planted at the low and normal densities. Seed was sown in north-south oriented rows.

Treatments were arranged in a complete block design with two replicates in 2008 and 2009, and four replicates in 2010. The size of each plot was 7.5 m × 15 m. Water and nutrients were supplied as needed according to local standard cultivation. Prior to planting, the field was irrigated and fertilized with 187 kg ha^{-1} of urea and 375 kg ha^{-1} of compound fertilizer ($N:P_2O_5:K_2O$ = 15%:15%:15%). At anthesis, the field was irrigated again and fertilized with 195 kg ha^{-1} of urea. Weeds were removed by hand to avoid any herbicide influence on plant growth. No plant disease, pest or stress symptoms were observed. Mean daily air temperature was calculated as the average of daily maximum and minimum air temperatures collected from a standard weather station at an approximate distance of 5.6 km from the experimental field.

2.2. Sampling and measurement

The emergence date of each treatment was recorded when 50% of its plots at emergence stage (Ritchie and Hanway, 1982). At least 20 plants in each plot representing average plants were tagged at 10 d before silking (the first silk visible of the apical ear). The silking date of the apical ear was recorded for each tagged plant and the subapical ear was bagged prior to silking to prevent pollination. The silking date of each treatment was the mean silking date of its tagged plants. Sowing, emergence and silking dates for each treatment are shown in Table 1. In all three years, beginning at 7 d after silking (DAS), the apical ear of one plant per plot was sampled every 7–10 d until the kernels reached physiological maturity, which was defined as the mean moisture content of all sampled kernels of a given hybrid × density treatment ≤ 350 g kg^{-1} (Sala et al., 2007b). However, the sampling of the normal density treatment for the hybrid ND108 in 2008 was stopped earlier because of partial plant lodging due to strong winds. After sampling each ear was enclosed in a plastic bag and transported to the laboratory in an insulated cooler. In 2008 and 2009, one row of kernels for each ear, which typically consists of sixteen rows for both hybrids, was selected. Each kernel was numbered in sequence starting at the bottom of the ear and then sampled. Aborted kernels in the apical section were not sampled. Fresh weight of each kernel was determined by a balance with an accuracy of 0.001 g. Dry weight of each kernel was measured with a balance that had an accuracy of 0.0001 g after drying in a forced air oven at 80 °C for at least 96 h. In 2010, ten kernels from the 10th–15th positions and ten kernels from the apical region of each ear from the four replicates were sampled. The fresh and dry weights of each group of ten kernels were weighted.

2.3. Data analysis

To compare the growth of kernels at different positions of maize ear, four sections were defined in each kernel row: basal (B), lower third (L), upper (U) and apical (A) section. These corresponded to