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Effect of maize plant morphology on the formation of apical kernels at different sowing dates and under different plant densities

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ABSTRACT

In maize (*Zea mays* L.), final grain yield is largely determined by kernel number at harvest. The goal of this research was to assess the source of kernel loss and identify the main factors in the process of kernel formation among maize hybrid genotypes comprising semi-compact (JH5) and compact (LD9066) genetic backgrounds (with contrasting tolerance to stand density) under field conditions. Field experiments were conducted in 2014 and 2015. Two hybrids were grown at three sowing dates (early April: SD1, early May: SD2, and late May: SD3) and under three plant densities: D1 (5.25 plants m^{-2}), D2 (6.75 plants m^{-2}), and D3 (8.25 plants m^{-2}). Two sources of kernel loss were assessed and associated with 1) silks failing to emerge from the husk 7 days after silking (loss1) and 2) kernel abortion during the grain-filling period (loss2). The results demonstrated that floret number was significantly influenced by maize hybrid: the semi-compact maize hybrid JH5 had more florets than did the compact maize hybrid LD9066. However, the final kernel number per plant (FKNP) of JH5 was slightly lower than that of LD9066. JH5 had a larger value for both loss1 and loss2 than did LD9066 (22.6% vs 11.9% and 21.0% vs 12.1%, respectively). Moreover, sowing date and plant density also significantly influenced the source of kernel loss. SD1 exhibited a greater value of loss1 than did SD2 and SD3 (24.9%, 15.8% and 11%, respectively) but a lower value of loss2 than did SD2 and SD3 (10.0%, 20.6% and 19.6%, respectively). Plant density had no significant effect on loss1; however, the highest plant density (D3) resulted in the highest loss2 among three plant densities (9.4%, 15.9% and 25.9%). The dynamics of visible silking showed that JH5 requires more time (+1.5 days) to reach 50% maximum visible silks than does LD9066 and has a lower proportion of maximum visible silks at the seventh day after silking. In addition, the apical kernels of JH5 had a relatively longer Dmax (days needed to reach the maximum grain-filling rate) and greater Gmax (maximum grain-filling rate) than did those of LD9066 (+0.5 day and +3.5 mg $kernel^{-1}$ d^{-1}, respectively). However, the Wmax (kernel weight at the maximum grain-filling rate) and P (active grain-filling period) of JH5 were much lower than those of LD9066 (-6.4 mg $kernel^{-1}$ and −8.2 days, respectively). Compared with the semi-compact hybrid, the compact hybrid showed an enhanced ability to resist abiotic stress tolerance, with good fertilization synchronization and a low percentage of kernel abortion. These above-mentioned traits should be considered in breeding programs to further increase the maize yield in China.

1. Introduction

Agricultural production must improve to meet the increasing demand for the food, fuel and feed of a rapidly growing world population (Tilman et al., 2002). As one of the staple grain crops grown worldwide, maize (*Zea mays* L.) exhibits high yield potential; however, its yield has not exceeded 70% of the yield potential in any of the major maize production regions worldwide (Lobell et al., 2009). Therefore, improving the understanding of factors that influence maize yield will help enhance maize production and food security.

In China, maize morphological traits have changed during the last 50 years. Enhanced plant density tolerance may be strongly dependent on improved morphology, i.e., plant lodging resistance (Hammer et al., 2009; Ci et al., 2011). Ma et al. (2014) concluded that yield improvement in maize was mainly the result of increased plant density tolerance (Ma et al., 2014). A similar trend has been reported in the U.S. Corn Belt, Brazil and Argentina (Duvick, 2005; Di Matteo et al., 2016). Moreover, several studies have indicated that older hybrids have as much yield potential as do newer ones when grown under stress-free conditions; yield differences between old and new hybrids are mainly

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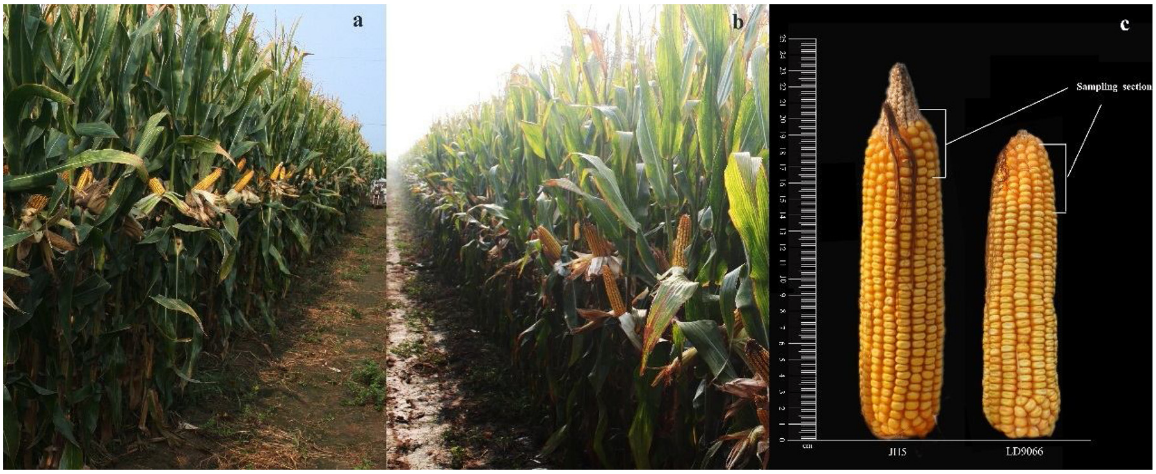

Fig. 1. Field images at the maturity stage (R6) before harvest (a and b) and samples of ear types after harvest (c) of different plant morphologies: the semi-compact hybrid JH5 (a) and compact hybrid LD9066 (b). Shot by Cannon EOS 400D.

rooted in plant density tolerance (Echarte et al., 2000; Sangoi et al., 2002). However, Wang et al. (2011) summarized that the yield of Chinese single-cross maize hybrids has primarily been achieved via increased yield per plant, which contrasts with the strategy of selecting for more stress-resistant plants in the United States, Argentina, Brazil and Canada (Wang et al., 2011). Currently, the most widely used planting density of maize in China is less than 60,000 plants ha^{-1}; in contrast, the planting density routinely used today in the U.S. Corn Belt is more than 75,000 plants ha^{-1}.

Kernel number accounts for most of the variation in maize grain yield components, especially for the apical kernels, which have the lowest priority for assimilate supply (Chen et al., 2013). Previous studies have summarized the physiological mechanisms of maize kernel formation and the response of kernel number to various abiotic stresses, such as shade (Hashemi-Dezfouli and Herbert, 1992), crowing for (Vega et al., 2001; Pagano and Maddonni, 2007), heat (Cicchino et al., 2010b), water and nitrogen deficiency (Cakir, 2004; D'Andrea et al., 2008). In general, poor distribution of assimilates to the maize ear limits kernel formation, and stress-resistant genetic backgrounds of maize hybrid play a key role during this process (Rattalino Edreira and Otegui, 2012; Rattalino Edreira et al., 2014).

The dynamics of silking and the grain-filling process have been carefully summarized, and it has been documented that the number of florets is essential for determining final kernel number. Floret number relies heavily on the breeding process (genetic background) instead of variation in agronomic management, such as plant density, sowing date, water, and nitrogen stress (Bassetti and Westgate, 1993a), although these agronomic factors will largely determine kernel numbers at harvest. Several studies have shown that synchronous pollination (a decrease in the duration of the anthesis-silking interval (ASI)) improves kernel set in maize silking dynamics (Carcova et al., 2000; Echarte and Tollenaar, 2006; Uribelarrea et al., 2008). Typically, researchers detect an increase in the ASI when maize is subjected to abiotic constraints such as water and nitrogen deficiencies (Hall et al., 1982; Jacobs and Pearson, 1991). However, recent research focused on the response of a temperate hybrid to high-temperature stress imposed during the late-vegetative period found no increase in ASI (Cicchino et al., 2010b). Reduced biomass partitioning to the ear caused by abiotic stress (water and nitrogen deficiencies) results in an increased ASI. Several studies have also found that kernel growth rate varies at different floret positions and that apical kernels on the rachis initiate their growth 4–5 days after the basal kernels do (Tollenaar and Daynard, 1978; Chen et al., 2013). Compared with basal kernels, later-fertilized kernels typically have a lower growth rate and a shorter duration of the linear grain-filling period. The various studies previously described have improved our understanding of the formation of kernel set. Apical kernels are most likely to be affected by various abiotic stresses. However, information about the formation of apical kernels is still inadequate, especially for maize hybrid varieties with different genotype backgrounds, such as stress resistance that results in better withstanding against higher plant densities. Therefore, a closer examination of the source of kernel loss and associated physiological mechanisms is needed to further improve maize grain yield.

The objective of this study was to investigate 1) the source of kernel loss (mainly for apical kernels) for maize hybrid varieties with contrasting tolerance to plant density at different sowing dates and under different plant densities and 2) physiological determinants involved during this process, such as flowering dynamics and grain-filling characteristics of apical kernels.

2. Materials and methods

2.1. Experimental design

Field experiments were conducted in 2014 and 2015 at Wuqiao Experimental Station (37°41′N, 116°37′E) of China Agricultural University; the soil is a clay loam (source of soil classification: ISS-CAS 2003). Two high-yielding single-cross maize (*Zea mays* L.) hybrids widely used for local summer maize production, Jinhai-5 (JH5) and Ludan-9066 (LD9066), were included in the study. The two varieties have a similar growth period that ranges from 98 to 103 days from sowing to physiological maturity when grown in the summer season. JH5 and LD9066 were first released in 2003 and 2011, respectively. The number of florets per ear is usually more than 800 for JH5 (larger ear size) and fewer than 650 for LD9066 (small ear size) (Fig. 1). The plant density recommend by the seed company is 52,500 plants ha^{-1} for JH5 (a semi-compact hybrid variety) and 67,500 plants ha^{-1} for LD9066 (a compact hybrid variety). Three sowing dates (early April [SD1], early May [SD2] and late May [SD3]) and three different plant densities were evaluated in this study. The row spacing was 0.55 m, and the plant spacing was 0.32 m for the low-density treatment (5.25 plants m^{-2}), 0.28 m for the normal-density treatment (6.75 plants m^{-2}), and 0.22 m for the high-density treatment (8.25 plants m^{-2}). The normal plant density represented the plant density typically used by local producers or the recommended plant density by seed companies.

Treatments were distributed in a split-split-plot design, with sowing date, hybrid, and plant density in the main plot, subplot, and sub-subplot, respectively. All treatments consisted of three replicate plots that were 9 m long by 7 m wide. The plots were sown by hand and then thinned to the desired density at the V5 growth stage. Water was