THE CROP JOURNAL 5 (2017) 305–316

Crop Science Society of China

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Response of phenology- and yield-related traits of maize to elevated temperature in a temperate region

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ARTICLE INFO

Article history:
Received 8 September 2016
Received in revised form
26 December 2016
Accepted 3 February 2017
Available online 9 March 2017

Keywords:
Maize
Elevated temperature
Phenology
Yield
Yield-related traits

ABSTRACT

Extreme high temperatures detrimental to maize production are projected to occur more frequently with future climate change. Phenology and yield-related traits were investigated under several levels of elevated temperature in two early-maturing hybrid cultivars: Junda 6 (grown in northeastern China) and Chalok 1 (grown in South Korea). They were cultivated in plastic houses in Suwon, Korea (37.27°N, 126.99°E) held at target temperatures of ambient (AT), AT + 1.5 °C, AT + 3 °C, and AT + 5 °C at one sowing date in 2013 and three different sowing dates in 2014. Vegetative and reproductive growth durations showed variation depending on sowing date, experimental year, and cultivar. Growth duration tended to decrease, but not necessarily, with temperature elevation, but somewhat increased again above a certain temperature. High temperature-dependent variation was greater during grain filling than in the vegetative period before anthesis. Elevated temperature showed no significant effects on duration or peak dates of silking and anthesis, and thus on anthesis–silking interval. Grain yield tended to decrease with temperature elevation above ambient, showing a sharper linear decrease with mean growing season temperature increase in Junda 6 than in Chalok 1. The decrease in kernel number accounted for a much greater contribution to the yield reductions due to temperature elevation than did the decrease in individual kernel weight in both cultivars. Individual harvestable kernel weight was not significantly affected by temperature elevation treatments. Kernel number showed a linear decrease with mean growth temperature from early ear formation to early grain-filling stage, with Junda 6 showing a much severer decrease than Chalok 1. Kernel number reduction due to temperature elevation was attributable more to the decrease in differentiated ovule number than to the decrease in kernel set in Chalok 1, but largely to the decrease of kernel set in Junda 6.

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Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.

http://dx.doi.org/10.1016/j.cj.2017.01.004

1. Introduction

Maize is a principal staple food crop that is grown worldwide, ranks first in worldwide production, and is quite adaptable to high temperature and dry environment in comparison to C_3 crops. However, global warming has already exerted substantial negative impacts on maize yield in many regions [1], lowering global maize yield by 4% over the 29-year period from 1980 to 2008 [2]. Although historical warming has led to large annual increases in *maize* yield in some regions [3], even more-dramatic impacts on maize yield and food security are expected under future climate regimes: in the tropics and subtropics by the end of this century the growing season temperatures will exceed the most extreme temperatures recorded in the past century and in temperate regions the hottest seasons on record will represent the future norm in many regions [4]. Higher growing-season temperatures will reduce maize yield in diverse regions of the world and exacerbate food insecurity [5–9]. Chen et al. [10] reported that daily minimum temperature was the dominant factor in maize production. Maize yield was significantly correlated with daily minimum temperature in May and September.

Maize yield is determined by the combination of two yield components: kernel number and individual kernel weight [11], which are highly influenced by environmental conditions during the flowering stage [12,13] and grain-filling period [12,14], respectively. Reproductive organs have a considerably lower temperature threshold for damage by heat stress than other organs [15]. Yield reduction due to high temperature during reproductive phase is associated with a decrease in kernel number and weight. High temperature reduces the number of kernels per ear by reducing the number of ovules that differentiate, are fertilized, and develop into kernels [16,17] and by increasing kernel abortion during kernel development [18]. High temperature-induced failure of fertilization of ovule is attributed primarily to the abnormal development of male reproductive tissues, which are more sensitive to heat stress than female reproductive tissues [19]. Pollen viability and *in vitro* germination are reduced under high temperature [16,17,19,20]. Asynchronous timing of anthesis and silking is also an important factor leading to decrease of fertilized ovules [21] and is known to be highly influenced by drought stress [22,23] and heat stress [24,25]. Heat stress during the early stage of kernel development disrupts endosperm development and leads to abortion or premature cessation of growth [18]. The latter authors reported that long-term heat stress, applied at 35 °C for 8 days beginning three days after pollination, resulted in abortion of 97% of kernels, whereas short-term heat stress at 35 °C for 4 days resulted in less abortion, of 23%, owing to a recovery of kernel growth and water content following heat stress. Kernel weight is determined by biomass accumulation within kernels during the grain-filling period that is dependent mainly on kernel growth rate and the duration of the effective filling period [26,27], both of which are affected by temperature and assimilate availability [14,28,29]. High temperature stress during this period reduces the duration of grain filling [30], potential kernel size by inhibiting endosperm cell division and amyloplast biogenesis [31,32], and assimilate availability [33], leading to reduced final kernel weight [33]. Heat stress effects on final kernel weight were larger when the stress occurred during the first half of effective grain filling than when it occurred around flowering, and larger for temperate than for tropical hybrids [33].

As reviewed above, heat stress during the crop reproductive period exerts negative effects on yield-determining processes and can be a critical factor detrimental to maize productivity under projected future climatic conditions. However, the severity of these effects and the yield-related traits responsible for the yield reduction anticipated under future climatic conditions have not been well addressed by experiments in temperate regions. The objectives of this study were to investigate the responses of maize phenology, yield-related traits, and yield to elevated air temperature conditions in a temperate region.

2. Materials and methods

2.1. Experimental setup

A series of experiments were performed during the growing season of maize in temperature-controlled houses covered with polyethylene film at the experimental farm of Seoul National University (37.27°N, 126.99°E), Suwon, Korea in 2013 and 2014.

2.1.1. Cultivars and cultivation

Test varieties were two hybrid cultivars, Junda 6 (early-maturing) and Chalok 1 (very early-maturing). Junda 6 and Chalok 1 were bred at the Maize Research Institute, Heilongjiang Academy of Agricultural Science, China and the National Institute of Crop Science, Korea, respectively. Maize is generally planted from the first 10 days of April to the middle 10 days of July in South Korea. The two cultivars were transplanted on June 7 in 2013 and June 2, June 17, and July 1 in 2014. Wagner (1/2000a) pots were filled with equal amounts of soil. The cultivars were transplanted to the pots around the V2 stage and grown with sufficient bottom watering. N-P-K fertilizer of 0.9–1.5–1.5 g per pot was applied at transplanting and the same amount was additionally applied on July 1 in 2013. In 2014, N-P-K was applied at 0.9–1.5–1.5 g per pot at transplanting and 0.9–0–0 g per pot and 0.90–0.75–0.75 g per pot were additionally applied after respectively four and six weeks from initial fertilization.

2.1.2. Temperature treatments

Five pots for each cultivar were transferred to and grown in four plastic houses held at the target temperatures of ambient temperature (AT), AT + 1.5 °C, AT + 3 °C, and AT + 5 °C. During the growing season, the air temperature in each plastic house was monitored and held at the target temperatures by automatic control of side and roof windows, ventilation fans, and a hot-air blower, using a data logger (CR1000, Campbell Scientific Inc., Logan, UT, USA) equipped with temperature and relative humidity sensors (model 41382, RM Young Company, Traverse City, MI, USA) and installed in an well-ventilated radiation shield (Fig. 1).