Heat Stress in Maize: Response of Grain Yield Components in Hybrids of Contrasting Genetic Background

FAUBA

Rattalino Edreira, J.I.*; Maddonni, G. A.; Otegui, M. E.

Depto. de Producción Vegetal. IFEVA-CONICET. Buenos Aires, Argentina. *rattalino@agro.uba.ar

CONICET

INTRODUCTION

Studies on climate change forecast an increase in mean air temperature and heat stress events. The effect of heat stress on plant metabolism depends upon intensity and duration of supra-optimum temperatures, in combination with the rate of temperature increase (Wahid et al., 2007). The impact on economic yields of grain crops (e.g. maize, Zea mays L.), however, depends upon the developmental stage of the crop at the time of stress (Hall, 1992). In environments where this type of stress is frequent (e.g. tropical and sub-tropical), a combination of escape and tolerance strategies are used for successful crop production. The former are those aimed to avoid the occurrence of critical periods (e.g. flowering) during heat stress events, and include the correct selection of sowing date and cycle duration. The latter involve the selection of hybrids well adapted to these environments (i.e. performance). There is, however, little knowledge on the responses of the physiological determinants of grain yield to heat stress, which include biomass production and its partitioning to reproductive organs.

The aim of this study was to evaluate the effect of two temperature regimes during three different growth stages on maize grain yield determination. Three hybrids of contrasting genetic background were analyzed.

MATERIALS AND METHODS

Field experiment during 2008-2009 at the Department of Plant Production of the University of Buenos Aires (35°35´S and 59°29´W), Argentina.

Crop husbandry: Plant density: 9 pl m^{-2}; Plot size: 6 rows, 0.7 m apart and 10 m length; Fertilization: 200 kg N ha^{-1} at V_6; Irrigation: Water availability of the uppermost 1 m of soil near field capacity by means of drip irrigation; permanent control of pests, weeds and diseases.

Treatments: factorial combination of (i) **two temperature regimes: [T_H] heated** (air temperature at ear level >35 ºC around noon); **[T_C] non-heated control**; (ii) **three different 15-d periods: [GS1] Pre-silking (V_{15}-R_1), [GS2] Post-silking (R_1-R_2), and [GS3] Grain filling (R_2-R_2+15d)**; and (iii) **three corn hybrids of contrasting genetic background: [Te] temperate, [Tr] tropical, and [TeTr] temperate x tropical**. Treatment areas (6 m^{-2}) were enclosed with polyethylene film (100-µm thickness) fixed to wood sticks (laterals and roof), yielding rigid shelters of 3.5 height. Heating depended upon the greenhouse effect of the polyethylene enclosure and the combination of an electric fun+heater unit. The unit was programmed for raising temperature up to 40 ºC at ear level between 08:00 and 12:00hs. GS1 and GS2 were hand-pollinated to avoid negative pollen viability effects on kernel set.

Experimental design: split-plot design, with $GS_n \times$ Hybrid in the main plot and temperature regime in the subplot. There were three replicates.

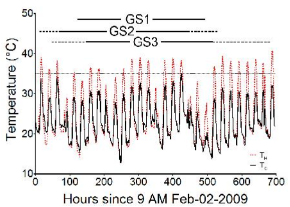
Measurements: Air temperature at ear height (T_X), infrared plant temperature (ear leaf, ear, tassel, stem), flowering dynamics (anthesis and silking evolution), plant nitrogen evolution by SPAD (registered for several leaves in each measured plant), light interception, biomass production (plant and ear), plant grain yield (PGY), kernel number per plant (KNP), kernel weight evolution and final kernel weight (KW).

Computations: ear growth rate during the critical period for kernel set (EGRcp), radiation use efficiency during pre-silking (EUR_{PRE}) and post-silking (EUR_{POST}) periods, grain filling rate during active grain filling, grain filling duration, and harvest index (HI).

RESULTS

STRESS CHARACTERIZATION

- All T_H treatments were exposed to T_X > 35 ºC for at least 9 days (fig. 1).
- At noon of a heated day, difference in T_X between T_H and T_C was 5.94 ± 3.4 °C. A maximum T_X of 40.7 °C was registered (fig. 1).
- Air temperature of T_H treatments increased from ground to tassel level. Consequently, infrared temperature was higher for topmost (tassel) than for lowermost (stem) organs (fig. 2).



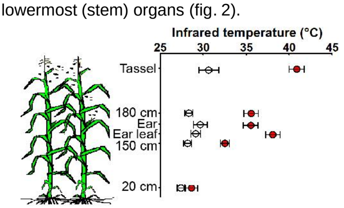


Figure 1: *Hourly T_X evolution along treatment period. Horizontal bars represent the average heating period of each treatment (GSn).*

Figure 2: *Infrared temperature of different organs registered at midday during treatment period. Red and white symbols represent T_H and T_C treatments, respectively. Bars indicate a CI of 95%.*

FLOWERING DYNAMICS

- All flowering events were delayed in response to supra-optimum temperatures applied during GS1 (Fig. 1), but the effect was larger on 50% anthesis date than on 50% silking date.
- The proportion of plants that reached anthesis was reduced for T_H plots of Te (0.64 ± 0.02) and Tr (0.76 ± 0.04) hybrids, but the proportion that reached silking was reduced only in Te (0.83 ± 0.02).

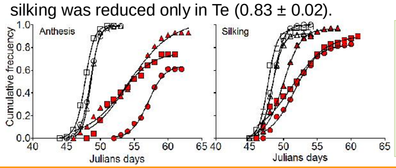


Figure 3: *Anthesis and silking dynamics of T_H (red symbols) and T_C (white symbols) plants in GS1. Circles, triangles, and squares represent Te, TeTr, and Tr hybrids, respectively. Lines represent fitted sigmoid models (r^2≥0.987).*

PHOTOSYNTHESIS RELATED TRAITS

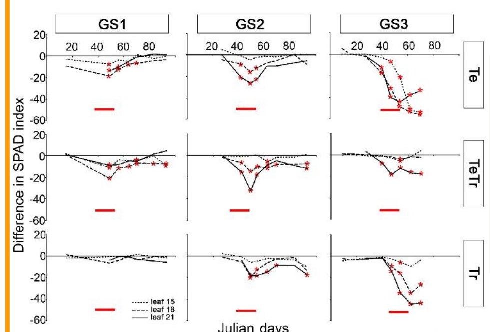


Figure 4: *Difference in SPAD index between T_H and T_C treatments for different leaf positions along the plant. Data correspond to all hybrids and heating periods (horizontal red bar). Asterisks indicate differences between T_H and T_C (CI of 95%).*

- During GS1, young leaves were less damaged (fig. 4, GS1) by heat stress than old leaves.
- During GS3, uppermost leaves were the most affected by heating (fig. 4).

- Heat stress did not affect light interception efficiency, but caused a decline in biomass production (data not shown). Consequently, RUE decreased for all T_H plots (fig. 5).
- RUE_{PRE} decreased for all T_H plots during GS1, and recovered after heating (i.e. RUE_{POST}) only for the Tr hybrid (fig. 5).
- Heat stress at GS2 reduced RUE_{POST} for all T_H plots.

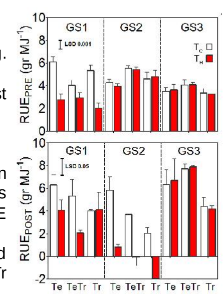


Figure 5: *Pre (RUE_{PRE}) and post (RUE_{POST}) silking radiation use efficiency of all treatments.*

GRAIN YIELD DETERMINATION

- KNP was the grain yield component which best explained PGY (fig. 6A). There was a significant (p=0.0069) STAGE*HYB*TEMP interaction for KNP. It was severely affected by heat stress at (i) GS2 for Te (22 kernels plant^{-1}), and (ii) GS1 for Te and TeTr. All the variation detected for KNP was well explained by the variation observed in EGRcp (y= 460+114.x^{-1}, r^2=0.80; fig. 6B).

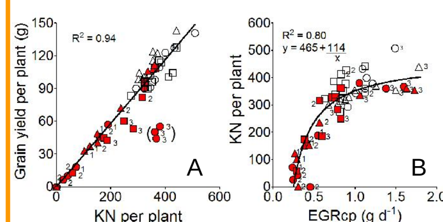


Figure 6: *Relationship between (A) PGY and KNP, and (B) KNP and EGRcp. Circles, triangles, and squares represent Te, TeTr, and Tr hybrids, respectively. Each point represents the mean value of the subplot. Numbers next to symbols represent the corresponding growth stage (GSn). Data in parenthesis were not included in the fitted model*

- PGY did not differ among T_C plots, but a significant (p=0.01) STAGE*HYB*TEMP interaction was detected (fig. 7, inset). Maximum PGY (107 g plant^{-1} ± 12.6) corresponded to all T_C plots and to T_H plots of TeTr-GS3 and Tr-GS1 (fig. 7). T_H plots of Te-GS2 had the lowest PGY (5.6 g pl^{-1}).
- Variation in PGY was explained (r^2=0.94) by variation in HI (fig. 8).
- There were HYB*TEMP (p=0.016) and STAGE*HYB*TEMP interactions (p=0.10) for KW (fig. 7). The Te hybrid was the most affected by heat stress (34% decrease in KW as compared to T_C). Heat stress at GS3 and GS2 reduced KW (228 mg and 229 mg, respectively), in contrast to GS1 (297 mg).

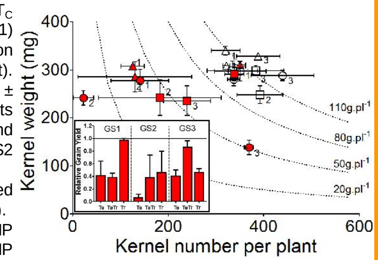


Figure 7: *Relationship between KW and KNP. Symbols as in fig. 6. Bars represent the SEM. Dotted lines indicate constant grain yield levels.*

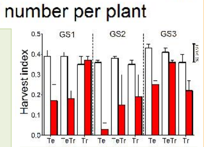


Figure 8: *Harvest index per plant for all treatments.*

GRAIN FILLING

- Temperature regimes during GS1 and GS2 did not affect the physiological determinants of KW (data not shown).
- Heat stress during GS3 affected grain filling duration of Te and Tr (-44% and -19% as compared to T_C, respectively; fig. 9 and 10).
- No significant differences were detected among treatments for grain filling rate (figs. 9 and 10).

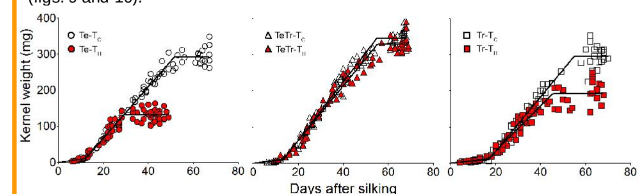


Figure 9: *Kernel weight evolution of all hybrids heated during GS3. Data represent values from individual sampled ears. Lines represent fitted three-line models (r^2≥0.91)*

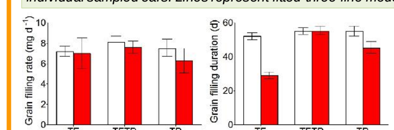


Figure 10: *Grain filling rate and grain filling duration of plants heated during GS3. Columns represent mean values of control (white) and heated (red) treatments. Bars indicate the CI of 99%.*

CONCLUSIONS

- **Heat stress reduced PGY as a result of a decrease in KNP and KW**. The magnitude of the reduction in grain yield depended upon the developmental stage of the crop at the time of stress (i.e. GS2>GS1>GS3).
- KNP was the grain yield component which best explained PGY. **KNP was severely affected by heat stress at (i) GS2 for Te and (ii) GS1 for Te and TeTr.** The variation in KNP was well explained by the variation in EGRcp**.**
- **KW was reduced by heating performed during GS3 due to a decrease in grain-filling duration**, but genotypic variation was detected in the response of this trait.

References: Hall, A.E. (1992). Plant Breed. Rev. 10:129-168.; Wahid A., S. Gelani, M. Ashraf y M.R. Foolad (2007). Environmental and Experimental Botany