High temperature effects on development and floret sterility of diverse sorghum lines

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Abstract

Sorghum *(Sorghum bicolor L. Moench)* is grown as a dryland crop in semiarid subtropical and tropical environments where it is often exposed to high temperatures. The incidence of exposure to high temperature is likely to increase with global warming and climate change. High temperature can have significant effects on growth, development, and yield. Damaging effects on development of reproductive organs have been reported for sorghum. The objective of this study was to examine the effect of high temperature on pollen viability and seed-set and explore its genotypic variability. Eighteen diverse sorghum genotypes were grown at day/night temperatures of 32°C/21°C (optimum temperature, OT) and 38°C/21°C (high temperature, HT) in controlled environment chambers. HT significantly reduced pollen viability and seed-set percentage of all genotypes. Genotypes differed significantly in pollen viability percentage (17% to 63%) and seed-set percentage (7% to 65%). There was a strong and positive correlation between pollen viability and seed-set percentage (R^2= 0.93, n=36, P<0.001), suggesting a causal association. The observed genetic variation in these traits could be exploited through breeding to develop heat tolerant varieties for future climates.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the world's major cereal crops, providing food, feed, and potential biofuel across a range of environments and production scenarios (Smith and Frederiksen 2000; Kresovich 2005). It is also the major summer grain crop for stockfeed in NE Australia and is grown under dryland conditions with prevailing unreliable and variable precipitation and high temperature (Hammer and Muchow 1991). Higher temperature in such environments has the potential to adversely impact the economic viability of sorghum (Barnabas, Jager et al. 2008). Due to increasing greenhouse gas emissions, the global surface temperature is predicted to increase in coming decades in the range of 1.5-5.8 ºC (IPCC 2007; Brunsell, Jones et al. 2010). This increase is likely to affect the production of major cereal crops. Recent studies on sorghum have indicated that the impact of high temperature on growth and development of sorghum depends on the timing of stress occurrence, and reproductive stages are more sensitive to higher temperatures than vegetative stages (Hammer and Muchow 1994; Prasad, Boote et al. 2006; Prasad, Pisipati et al. 2008; Craufurd and Wheeler 2009). However, genotype by environment interactions are not fully understood and need to be further studied (Hammer and Vanderlip 1989). The objectives of this study are to (i) enhance understanding of high temperature effects on growth, development, pollen viability, and seedset of sorghum, and (ii) explore the extent of genotypic variation among various sorghum genotypes in response of pollen viability and seedset to high temperature.

Methods

Genetic material

A diverse set of 18 sorghum genotypes, provided by the DEEDI sorghum breeding program, was used in this experiment. The material included parents of mapping populations and elite lines that are parents of hybrids used in the sorghum breeding program. Two hybrids were included as checks.

Growing conditions

Experiments were conducted in two temperature controlled growth chambers at the *Commonwealth Scientific and Industrial Research Organisation* (*CSIRO*) controlled environment facility (CEF) at St Lucia, SE Queensland. Temperature control was fully automated. One room was set to a day/night temperature of 32°C/21ºC and the other to 38°C/21ºC. Temperature was increased gradually starting one hour after the light period started, until the maximum temperature was reached. Temperature declined gradually towards the end of the light period, until minimum temperature was reached one hour before lights were switched off. As a consequence, the two chambers differed in temperature only for six hours in the middle of the light period. Relative humidity was adjusted during the period temperatures differed between the two chambers to ensure similar vapour pressure deficit. The photosynthetic photon flux density at the canopy level was about 600 $\mu mol\ m^{-2}\ s^{-1}$.

Observations

Data on phenology (days from sowing to emergence, flag leaf emergence, and anthesis) were recorded. Plant height was measured in *situ* once 4, 8, 12, and 16 leaves were fully expanded on the main stem. The area of each leaf was determined by in *situ* measurements of its length and width multiplied by a shape factor of 0.69 (Lafarge and Hammer 2002). Pollen viability was measured using an in *vitro* pollen germination method. Panicles were harvested at physiological maturity and seed set was measured.

Pollen viability and seed set

At the onset of anthesis, pollen grains from each plant were dusted onto germination media in a petri dish just after the lights were switched on. The germination media consisted of 150 mg H_3BO_3, 500 mg $Ca(NO_3)_2\_4H_2O$, 200 mg $MgSO_4\_7H_2O$, 100 mg KNO_3 and 300 g sucrose dissolved in 1 L of deionised water to which 15 g of agar L^{-1} was added and slowly heated on a hotplate until the agar was completely dissolved (Tuinstra 2000; Prasad, Boote et al. 2006). The petri dish containing pollen grains was incubated in the dark for 45 minutes at 28°C. The pollen grains were then photographed under an Olympus stereo microscope at 100x magnification. After imaging, the photographs were modified for contrast using Adobe Photoshop Elements 2.0 software. The percentage of pollen germination was estimated by counting the total number of pollen grains and the number of germinated pollen grains. A pollen grain was considered germinated if the length of the pollen tube was greater than the diameter of the pollen grain.

Seed set

At physiological maturity, panicles were harvested and branches from the top, middle and bottom section of the panicle were collected. The number of florets in each branch was counted and then the number of viable and non-viable seeds was counted in each floret. The number of viable seeds divided by the total number of florets gave the percent seed set.

Results

Phenology and growth

Plate 1. Photograph showing similar leaf area but reduced plant height of a sorghum genotype under control temperature (32°C/21°C) and high temperature (38°C/21°C) conditions.

High temperature affected both vegetative and reproductive growth of sorghum genotypes. High temperature increased the developmental rate (days to emergence, to flag leaf and to anthesis) on average across all genotypes. It significantly reduced plant height but had no effect on leaf area (Plate 1).

Pollen viability and seed set

There were significant (P <0.001) effects of temperature on pollen viability (Figure 1). Under optimum temperature, pollen viability was around 70-80%. High maximum temperature decreased percentage pollen viability across all genotypes, but genotypes differed significantly in their response to HT. Under high temperature, pollen viability varied from 17% to 62%. The decrease in pollen viability was greatest in B35, followed by SC170-6-8, suggesting that those lines are highly susceptible to high temperature. The decrease in pollen viability was least in genotypes R9403463-2-1 and IS8525, suggesting that those lines were more tolerant to high temperature.

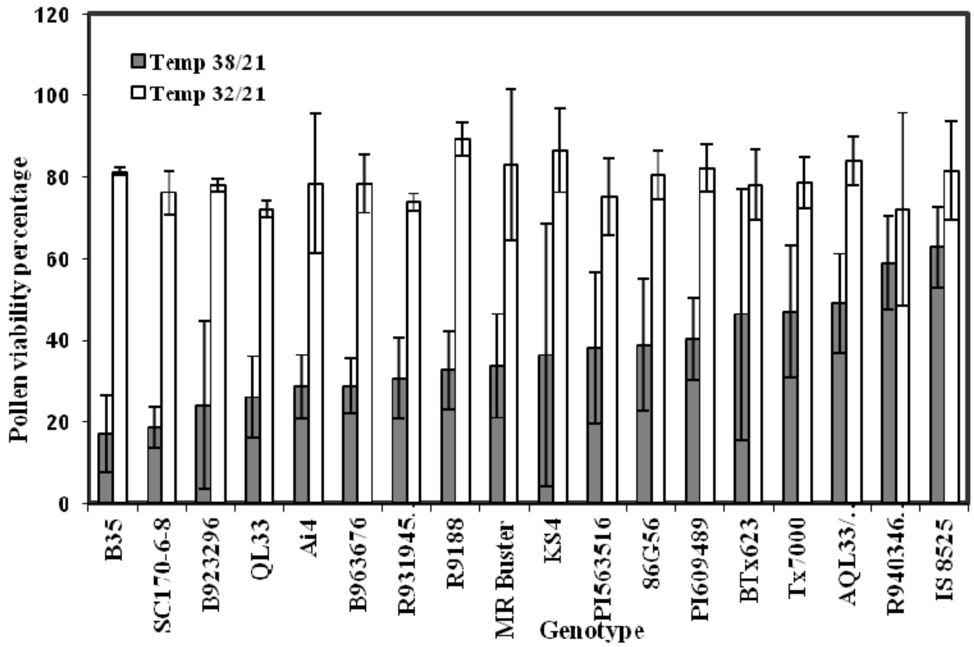

Figure 1. Influence of optimum temperature (OT, 32°C/21°C) and high temperature (HT, 38°C/21°C) on pollen viability

There was also a significant effect of high temperature on seed set (data not presented). On average, high temperature decreased the percentage of filled sites for all genotypes. The percent of seed set under high temperature ranged from 7.3% for B923296 to 61.5% for R9403963-2-1.

Correlation between pollen viability and seed set

There was a strong and positive linear relationship between pollen viability percentage and seed set percentage across genotypes ($R^2 = 0.93$). The relationship was independent of temperature, suggesting that a decline in pollen viability can affect seed set and therefore grain yield.

Conclusion

The evidence from this study indicates that an increase in temperature can have significant impact on sorghum production. High temperature causes lower pollen viability, resulting in lower seed set. This is likely to adversely affect seed number, leading to potentially significant reductions in grain yield. Hence, it is likely that the period prior to flowering, when pollen formation occurs, is critical for high temperature effects. However, there was evidence of genotypic difference among sorghum genotypes for pollen viability sensitivity to high temperature. This variability in pollen viability could be used as a potential screening method to develop high temperature tolerant genotype through breeding programs.

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