Does available soil water buffer transient high temperature stress in lentil?

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Abstract
Lentil production in arable, Mediterranean-type climates is limited by unreliable rainfall and the occurrence of heat waves during the reproductive phase. Under climate change predictions, there is an expectation of increasingly drier spring conditions and an increase in the frequency of heat waves. Consequently, there is a need to improve the adaptation of lentil, which is particularly sensitive to abiotic stresses. Improved yield stability through a combination of agronomic management and capturing benefits of genetic tolerance to abiotic stress such as transient high temperature is needed. In contributing to this goal we assessed the interaction of crop-available soil water and high temperature (flat pod stage) for a range of lentil genotypes. For lentil under ambient growing temperatures and high water availability, yield increased by 39% compared with low water treatments, however, high temperature (42°C day | 25°C night) caused grain yield across contrasting water regimes to be equivalent. Evidently increased water availability did not buffer the impact of high temperature. Across three lentil genotypes, high temperature caused grain number of PBA Bolt and 73838 to be significantly reduced by 36 and 53% respectively, however, for 71457, grain number was equivalent across heat treatments, which indicates that 71457 had relatively greater stability in maintaining grain number compared with the other genotypes. Overall, water availability to lentil appeared not to mitigate the impact of high temperature, however, a variation in the response of lentil across genotypes to high temperature provides promise for increasing the yield stability of lentil using breeding solutions.

Keywords
Climate change, drought, heat wave, pulses.

Introduction
For cool-season grain legumes, water-stress and high temperature (heat shock) are the most significant abiotic stresses that limit production worldwide (Siddique 1999). This is particularly the case in Mediterranean-type climates such as southern Australia where rainfall is characteristically low and unreliable (200 – 600 mm/year) and heat waves (three or more consecutive days of high maximum and minimum temperatures) during the reproductive phase are frequent. While crop water availability over the growing season is variable and tends towards terminal drought (water stress), heat stress occurs abruptly and can have a step change impact on grain yield. Under climate change, the severity and frequency of both stresses is expected to increase, with adverse effects on crop production (IPCC 2012). Together they are estimated to cause 50% of grain yield loss in pulse crops globally (Gaur et al. 2014).

Lentil is particularly sensitive during the reproductive phase to high temperature stress where heat waves cause pod and flower abortion and a significant reduction in grain yield and quality. The indeterminate growth habit of lentil, however, may provide this crop with some plasticity to recover by continuing to flower and set pods following a heat wave, provided complete senescence has not occurred (Vadez et al. 2012) and there is adequate water availability (Hall 1992). Consequently, understanding the interaction of crop water availability and heat wave effect on lentil during the reproductive phase is important in determining possible agronomic options for limiting the impacts of such abiotic stresses. Moreover, genetic tolerance to high temperature may also provide adaptation options in lentil. Screening for high temperature tolerance in lentil by Delahunty et al. (2015) has previously identified several genotypes with improved tolerance indicating an opportunity to utilise genetic variability within lentil. In this study we investigated the interaction of soil water availability during the growing period and transient high temperature stress to lentil under controlled conditions to determine if water supply buffers the impact of heat wave on grain number and yield.

Methods

Three lentil genotypes were tested for their response to water availability and transient high temperature applied during the reproductive phase. Genotypes PBA Bolt (Australian commercial cultivar), 71457 and 73838 (accessions collected in Jordan and Albania, respectively; Australian Grains Genebank) were selected due to stable yields under high temperature stress when screened for this trait in previous experiments (results not reported in this paper). The trial was sown in a naturally lit polyhouse at Horsham, Victoria on the 31/05/2015 (4 plants/pot) in a randomised complete block design with four replicates. Square pots (diameter 17 cm, depth 24 cm) were filled with a Vertosol clay (topsoil 0-10 cm layer) from the Wimmera, Victoria. The treatment design was four water combinations and two heat treatments, ambient and high temperature (42°C day| 25°C night) for 5 consecutive days during pod-filling. A controlled growth cabinet was used to apply heat and relative humidity was also regulated (day 20%, night 80%). The water regimes tested the combination of low and high soil water availability during the pre- and post-flowering period in factorial combination. The low water treatment was 20% of the plant available water capacity (PAWC) compared to 80% for the high treatment. The water regimes were switched (where relevant) from pre- to post-flowering with the onset of flowering. Ambient and growth cabinet (elevated) temperatures were recorded every 5 minutes using TinyTag Ultra 2 sensors TGU-4500 (temperature, relative humidity and dew point). At crop maturity, the above-ground biomass was harvested and total biomass, grain number and yield determined.

Results and Discussion

For lentil yield, there was a significant interaction between transient high temperature and post-flowering water availability. Under ambient temperature there was a significant increase in yield (39%) when water availability in the post-flowering phase was increased. In contrast for plants exposed to high temperature, yield was equivalent and significantly less across contrasting water regimes. This indicates that adequate soil water availability did not buffer the impact of high temperature. For the high and low water regimes (post-flowering) there was a reduction in yield of 47 and 43% respectively, due to high temperature (Figure 1). The impact of high temperature on grain yield may be linked with a reduction in grain number ($p = 0.127$) of 37 and 31% for the high and low water treatments respectively. In previous research, Erskine et al. (2011) found that in lentil, heat stress combined with low water availability had an additive impact on growth under field conditions. There was no significant interaction of pre-flowering water availability and heat treatment, however, high water during this period significantly increased grain yield by 17%, compared with the low water treatment.

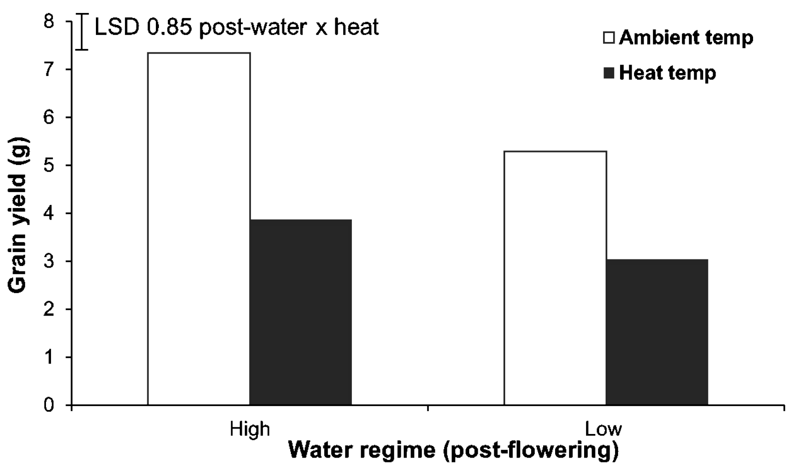

Figure 1. The response of lentil (grain yield, g/pot) to post-flowering water availability and high temperature at the reproductive phase. Yields are pooled for three genotypes, PBA Bolt, 71457, 73838. Interaction between post-flowering water regime and high temperature significant ($p = 0.045$).

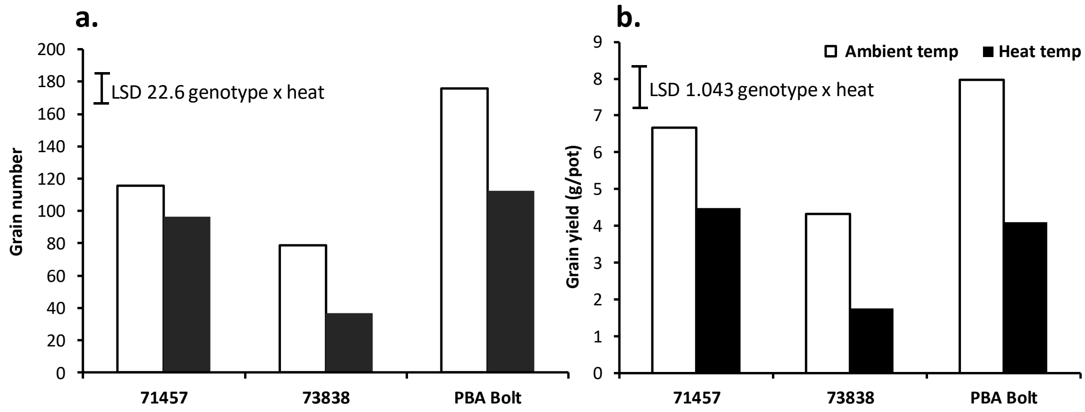

Figure 2. The response of grain number (a) and grain yield (b) to high temperature at the reproductive phase on lentil genotypes: 71457, 73838 and PBA Bolt. Water treatments are pooled (pre- and post-flowering). Interaction between grain number and high temperature significant (p = 0.015), grain yield and high temperature significant (p = 0.005).

Across the three genotypes, high temperature caused grain number of PBA Bolt and 73838 to be significantly reduced by 36 and 53% respectively, however, for 71457, grain number was equivalent across high temperature treatments (Figure 2b). This indicates that 71457 had relatively greater stability in maintaining grain number compared with the other genotypes. Under ambient temperature, absolute grain number of PBA Bolt was significantly higher than 71457 whereas under high temperature grain set was equivalent. For yield, there was a significant interaction of genotype and temperature treatment (Figure 2a) where the reduction due to heat was proportionately lower for 71457 (33%) compared with PBA Bolt (49%) and 73838 (59%). For grain size, there was a significant decrease for the three genotypes, due to high temperature. The timing of high temperature influences impact on yield components, where yield losses due to grain size tend to be greater soon after flowering (Prasad et al. 2008). This differs from Shrestha et al. (2006) who proposed lentil may adjust grain size to suit environmental conditions indicating that other environmental factors may influence the grain-filling process.

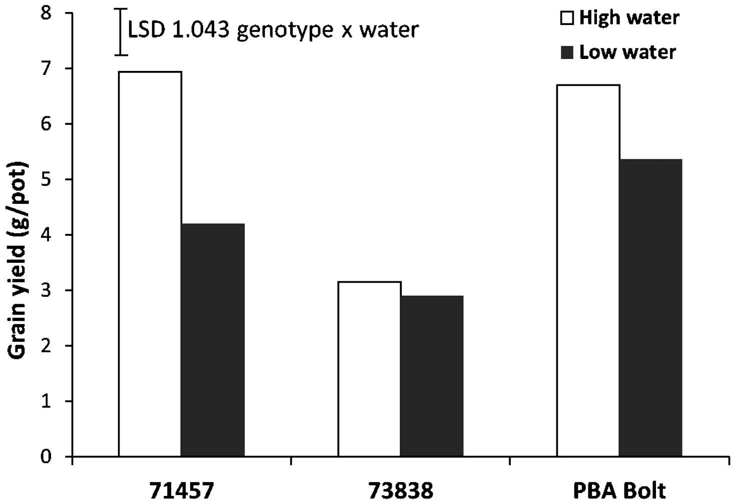

Figure 3. The response of grain yield to water availability post-flowering on lentil genotypes: 71457, 73838, PBA Bolt. High temperature treatments are pooled (heat stress and ambient air). Interaction between grain yield and high temperature was significant (p = 0.005).

There was a significant interaction between genotypes and post-flowering water availability on grain yield (Figure 3), where for PBA Bolt and 71457, yield was significantly reduced under low water (post-flowering), but was equivalent for 73838. The absolute grain yield of 73838 under high water was 53 and 55% lower than for PBA Bolt and 71457 respectively. Overall, this suggests that PBA Bolt was both high yielding and able to maintain yield under limited water in the post-flowering phase.

Conclusions

For lentil exposed to transient high temperature under a range of water regimes, soil water availability did not buffer the impact of high temperature occurring at the early flat pod stage. This was due to grain yield for plants with more water available being reduced to equivalent of that observed under low water regimes when heat was imposed to plants at the reproductive phase. This indicates that under high water growing conditions the indeterminate growth habit of lentil did not mitigate the impact of transient high temperature effects around the flat pod stage. For the three lentil genotypes, the grain number was significantly reduced for PBA Bolt and 73838 under high temperature, whereas the genotype 71457 maintained a relatively stable grain number across heat treated and control plants. The response of 71457 infers a level of heat tolerance for this genotype and more broadly the opportunity for maintaining yield stability of lentil under transient high temperature. Improving the heat tolerance and minimising the associated yield losses of lentil would assist in reducing production risk and enhance opportunity for cropping expansion to hotter, drier regions, such as the Victorian and South Australian Mallee.

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References

Delahunty AJ, Nuttall JG, Nicolas ME (2015). Genotypic heat tolerance in lentil. In: Proceedings 17th Australian Agronomy Conference. (http://www.agronomy2015.com.au/). Hobart, Tasmania, Australia.

Erskine W, Sarker A and Kumar S (2011). Crops that feed the world 3. Investing in lentil improvement toward a food secure world. Food Security 3, 127-139.

Gaur PM, Srinivasan S and Varshney RK (2014). Drought and heat tolerance in chickpea. Legume Perspectives 15-17.

Hall AE (1992). Breeding for heat tolerance. Plant breeding reviews 129.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. In: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Feild CB, et al. Eds. Cambridge, UK, and New York, NY, USA, Cambridge University Press.

Prasad PV, Pisipati S, Mutava R and Tuinstra M (2008). Sensitivity of sorghum to high temperature stress during the reproductive development. Crop Science 48(5), 1911-1917.

Shrestha R, Turner NC, Siddique KHM and Turner DW (2006). Physiological and seed yield responses to water deficits among lentil genotypes from diverse origins. Australian journal of agricultural research.

Siddique KHM (1999). Abiotic stresses of cool season pulses. In: TRIALS OF Ed. Birchip Cropping Group.

Vadez V, Berger JD, Warkentin T, Asseng S, Ratnakumar P, Rao KPC, Gaur PM, Munier-Jolian N, Larmure A, Vosin A-S, Sharma HC, Pande S, Sharma M, Krishnamurthy YL and Zaman MA (2012). Adaptation of grain legumes to climate change: a review. Agronomy for Sustainable Development 32, 31-44.