Hot Genes: exploring the genetic bases of wheat tolerance to heat, comparing methods and results

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Abstract

Wheat, the third most highly produced crop in the world and a staple for millions (FAOSTAT, 2022) is under threat due to temperature increases in major wheat-growing regions (Gaffen & Ross, 1998, Alexander et al., 2006, Hennessy et al., 2008), which is predicted to cause tremendous yield-loss (Asseng et al., 2011, 2015). Breeding of wheat for increased tolerance to heat might improve crop adaptation and minimize heat-stress associated yield losses , but requires better understanding of the genetic bases of heat tolerance in wheat.

Heat application methodology is fundamental to any genetic research and breeding at the crop level aiming to identify and characterize the genetic control of heat tolerance. Two of the major ways to mimic heat stress are growing plants in a controlled environment (with artificial heating at specific crop growth phases) and late-sowing in the field (if this is done later then the optimal sowing date it will mimic heat stress throughout all phases of crop growth). An example for the first type might be applying terminal heat stress during grain-filling, which has been shown to cause significant yield losses (Asseng et al., 2011). In contrast, late-sowing enables on-field characterization, but it also exposes the plants to non-optimal temperatures across its growth, which does not allow for characterization of responses to stage-specific heat stress.

Five studies utilizing the two aforementioned different methods of heat application on spring wheat segregating populations originating from heat-tolerant and heat susceptible parents. Four of these studies were selected as they use the same spring wheat heat-tolerant genotype, “Halberd”, as a parent plant , with three of the studies carried out in controlled conditions (Mason, et al., 2010, 2011 and Telfer et al., 2021) and one introducing heat stress using late sowing (for one heat-stress treatment) and normal sowing during a second, hotter year (for an additional heat-stress treatment) (Mason, et al., 2013). The fifth study used different spring wheat parents and applied heat stress via late-sowing (with optimized applied irrigation to ensure to avoid any confounded effect of drought) (Pinto et al., 2010). When comparing QTL detection, it was evident that none of the QTLs showed full consistency across all studies, however, a QTL on chromosome 3B was found in more than one study using the “Halberd” parent (with the “Halberd” parent allele conferring tolerance in two of the studies, when crossed with the susceptible “Karl92” (Mason, et al., 2011, 2013), and the heat-susceptible “Cutter” parent conferring the tolerant allele at a homologous chromosomal location in the Halberd x Cutter population in another study (Mason, et al., 2010)). This “Halberd” allele on chromosome 3B was heat-adaptive for canopy temperature depression, spike density, and yield and robust (present in all conditions) for biomass in the late-sowing study (Mason, et al., 2013). In the other two studies by Mason, et al. this QTL was heat-adaptive for kernel weight. This 3B QTL was identified in these studies despite the different heat-treatment methodologies used, giving it further support and highlighting it as a candidate for fine mapping and breeding efforts (Mason, et al., 2010, 2011, 2013). While this QTL does not appear in the “Halberd”-descended population of the study by Telfer et al. (2021) (controlled-conditions including artificial wind, which perhaps caused the inconsistency), it does align with robust QTLs for spikelets per spike from other (non-“Halberd”) populations in the Telfer et al. (2021) study. Furthermore, Pinto et al. (2010) (late-sowing) also found, using different (non-“Halberd”) spring wheat parents, a QTL (heat-adaptive for grain number, canopy temperature depression, and chlorophyll content and robust for yield) during grain-filling in a similar location on chromosome 3B, showing that, despite the fact that it does not appear in the “Halberd”-descended population of the Telfer, et al. study (2021), it is nonetheless a site of importance for heat tolerance traits and yield stability under heat stress. Further research on this region and similar QTL regions found across studies, especially those carried out under different conditions or using different proxies for heat-tolerance, can help pinpoint potential QTLs to be used in breeding work to improve wheat heat-tolerance in the face of climate change.

References

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D. B., Burn, J., Aguilar, E., Brunet, M., … Vazquez-Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*(D5). https://doi.org/10.1029/2005JD006290

Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., Kimball, B. A., Ottman, M. J., Wall, G. W., White, J. W., Reynolds, M. P., Alderman, P. D., Prasad, P. V. V., Aggarwal, P. K., Anothai, J., Basso, B., Biernath, C., Challinor, A. J., De Sanctis, G., … Zhu, Y. (2015). Rising temperatures reduce global wheat production. *Nature Climate Change*, *5*, 143–147. https://doi.org/10.1038/nclimate2470

Asseng, Senthold, Foster, I. & Turner, N. C. (2011). The impact of temperature variability on wheat yields. *Global Change Biology*, *17*(2), 997–1012. https://doi.org/10.1111/J.1365-2486.2010.02262.X

Gaffen, D. J. & Ross, R. J. (1998). Increased summertime heat stress in the US. *Nature 1998 396:6711*, *396*(6711), 529–530. https://doi.org/10.1038/25030

Hennessy, K., Fawcett, R., Kirono, D., Mpelasoka, F., Jones, D., Bathols, J., Whetton, P., Stafford Smith, M., Howden, M., Mitchell, C. & Plummer CSIRO, N. (2008). *An assessment of the impact of climate change on the nature and frequency of exceptional climatic events*. http://www.ag.gov.au/cca

Mason, R. E., Hays, D. B., Mondal, S., Ibrahim, A. M. H. & Basnet, B. R. (2013). QTL for yield, yield components and canopy temperature depression in wheat under late sown field conditions. *Euphytica*, *194*, 243–259. https://doi.org/10.1007/S10681-013-0951-X/FIGURES/3

Mason, R. E., Mondal, S., Beecher, F. W. & Hays, D. B. (2011). Genetic loci linking improved heat tolerance in wheat (Triticum aestivum L.) to lower leaf and spike temperatures under controlled conditions. *Euphytica*, *180*, 181–194. https://doi.org/10.1007/S10681-011-0349-6/FIGURES/4

Mason, R. E., Mondal, S., Beecher, F. W., Pacheco, A., Jampala, B., Ibrahim, A. M. H. & Hays, D. B. (2010). QTL associated with heat susceptibility index in wheat (Triticum aestivum L.) under short-term reproductive stage heat stress. *Euphytica*, *174*, 423–436. https://doi.org/10.1007/S10681-010-0151-X/FIGURES/3

Pinto, R. S., Reynolds, M. P., Mathews, K. L., McIntyre, C. L., Olivares-Villegas, J. J. & Chapman, S. C. (2010). Heat and drought adaptive QTL in a wheat population designed to minimize confounding agronomic effects. *TAG. Theoretical and Applied Genetics. Theoretische Und Angewandte Genetik*, *121*(6), 1001. https://doi.org/10.1007/S00122-010-1351-4

Telfer, P., Edwards, J., Norman, A., Bennett, D., Smith, A., Able, J. A. & Kuchel, H. (2021). Genetic analysis of wheat (Triticum aestivum) adaptation to heat stress. *Theoretical and Applied Genetics*, *134*, 1387–1407. https://doi.org/10.1007/S00122-021-03778-2/TABLES/4