Physiological Studies on the Response of Wheat to Short-term Heat Stress during Reproductive Development

A.S.M. HASIM MORSHED TALUKDER

B.Sc. Agric. (Hons), M.Sc. Agric. (Agronomy)

A thesis by **prior publications** submitted to The University of Adelaide, South Australia

In the fulfilment of the degree of DOCTOR OF PHILOSOPHY

School of Agriculture, Food and Wine

Faculty of Science

DEDICATION

I would like to dedicate my thesis

To our

Beloved late Parents

&

Beloved late daughter

Tahira Morshed TALUKDER

TABLE OF CONTENTS

ABSTRACT

In Mediterranean environments, cereal crops are often exposed to short periods of elevated temperatures in spring when crops are approaching flowering and grain filling. Most studies on heat stress have focused on crop responses to extended periods of high temperature under controlled environment (CE) conditions possibly due to difficulties in applying heat stress in the field. It is possible wheat may respond quite differently to heat stress imposed under field and CE conditions. Therefore, experiments were designed to develop a methodology to apply heat treatments in the field. Studies were also undertaken to compare the response of wheat genotypes to a single-day heat stress event in the field and CE conditions.

Wheat genotypes were exposed to heat stress for a single-day at two different stages, near flowering or green anther stage (H1), and early grain set or 7-10 days after anthesis (DAA) (H2) in 2009 and 2010. Heat treatment was applied in the field in a portable purpose-built heat chamber in which the temperature was steadily increased to a maximum of 35°C, which was maintained for 3 hours before being allowed to steadily decrease to the ambient temperature, like a typical natural spring heat event. Similar to the field studies, wheat genotypes were also exposed to a single-day heat event (35°C maximum) in the CE study. This single-day heat stress event caused a significant reduction in flag leaf chlorophyll content, peduncle water soluble carbohydrate (WSC), grain yield and yield components in both years. There was no significant difference between H1 and H2 for most of the measurements with a few exceptions.

The maximum WSC content was reduced by heat stress in all wheat genotypes. Heat stress (average of H1 and H2) reduced peduncle WSC content by 26% and mobilized WSC content by 15% across all studies. Mobilization of peduncle WSC content was also significantly

reduced by the heat stress treatments. Genotypes with high WSC such as CM9-6Y, CM9-4Y showed lower sensitivity to heat stress than Janz, which had the lowest peduncle WSC content. Heat stress accelerated the rate of loss of flag leaf chlorophyll content. A higher rate of senescence in 2009, which was warmer and drier than 2010, was associated with greater yield loss. Reduction in grain yield among the genotypes was negatively correlated ($r = -0.79$; $p<0.001$) with the rate of flag leaf senescence. Heat stress reduced post-heading duration and grain yield across genotypes and heat stress treatments was strongly correlated ($r = 0.80$; $p<0.001$ in 2009 and $r = 0.82$; $p<0.001$ in 2010) with post-heading duration. Standardized partial regression coefficient (*b*) showed that the contribution of grain number ($b = 0.786$) to the grain yield was higher than IGM ($b = 0.435$) in 2009. In contrast, IGM ($b = 0.665$) appeared to be a stronger contributor to the grain yield than grain number ($b = 0.443$) in 2010. Relative to the unheated control, heat stress caused only a small reduction in grain set in the florets *a* and *b* (5% each) but there was a significant ($p<0.001$) reduction in grain set in florets *c* (16%), *d* (31%) and *e* (68%). However, heat stress also caused a sharp decline in grain number in positions *a* and *b* in the distal spikelets of Janz and Gladius but not in other wheat genotypes. Averaged over the growing conditions, seasons and across florets positions, the reduction in grain set due to heat stress was greater in Janz (35%) than CM9-4Y (14%), followed by CM9-6Y (18%), Krichauff (18%) and Excalibur (26%). Similarly, when averaged over years and growing conditions and florets positions, the reduction in IGM by heat stress was higher in Janz (33%) than CM9-6Y (15%), followed by Krichauff (17%) and CM9-4Y (20%). Grain yield loss of different wheat genotypes was strongly correlated ($r = 0.91$; $p<0.001$) between the field and CE. The results of these studies showed that under field and CE conditions, Janz was consistently the most sensitive genotype to heat stress. In contrast, CM9-6Y, CM9-4Y and Krichauff appeared to be most tolerant to heat stress. Averaged over the two growing seasons and heat stress treatments, the reduction in grain yield was greater in Janz (25%) than in CM9-6Y and CM9-4Y (13% each), followed by Krichauff (16%) and Excalibur (18%).

It could be argued that selection of early headed wheat genotypes with slower rate of leaf senescence, longer post-heading duration, higher stem WSC reserves, and greater mobilization of WSC could be used to buffer grain growth and development under heat stress conditions, which are a common occurrence in the Australian wheat belt.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.
The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

1. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2013). Effect of short-term heat stress prior to flowering and at early grain set on the utilization of water-soluble carbohydrate by wheat genotypes. Field Crops Res. 147, 1-11.
2. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2014). Effect of short-term heat stress prior to flowering and early grain set on the grain yield of wheat. Field Crops Res. 160, 54-63.
3. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2014). Effect of short-term heat stress around flowering on grain set in different floret positions in wheat. PLOS ONE (Submitted).

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

A.S.M. Hasim Morshed Talukder. ...... **Date** 03.12.2014

PUBLICATIONS ARISING FROM THIS THESIS

1. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2013). Effect of short-term heat stress prior to flowering and at early grain set on the utilization of water-soluble carbohydrate by wheat genotypes. Field Crops Res. 147, 1-11.

2. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2014). Effect of short-term heat stress prior to flowering and early grain set on the grain yield of wheat. Field Crops Res. 160, 54-63.

3. Talukder, A.S.M.H.M., McDonald, G.K., Gill, G.S. (2014). Effect of short-term heat stress around flowering on grain set in different floret positions in wheat. PLOS ONE (Submitted).

4. Talukder, A.S.M.H.M., Gill, G.S., McDonald, G.K., Hayman, P.T., Alexander, B.M. (2010) Field evaluation of sensitivity of wheat to high temperature stress near flowering and early grain set. In: Dove, H., Culvenor, R.A., (Eds.). "Food Security from Sustainable Agriculture". Proceedings of the 15th Australian Agronomy Conference held in Lincoln, New Zealand from 15-18th November 2010.

5. Alexander, B.M., Hayman, P.T., Talukder, A.S.M.H.M., Gill, G.S., McDonald, G.K. (2010) Characterising the risk of heat stress on wheat: meteorology, climatology and the design of a field heating chamber. In: Dove, H., Culvenor, R.A., (Eds.). "Food Security from Sustainable Agriculture". Proceedings of the 15th Australian Agronomy Conference held in Lincoln, New Zealand from 15-18th November 2010.

6. Rebecca Leigh (2013) Mercury rising: turning up the heat for an answer to crop stress. New research measures the influence of short-term temperature extremes on crop quality and quantity. Ground Cover, Grains Research and Development Corporation (GRDC), Kingston, ACT 2604, Australia, July – August 2013, 105, p 11.

ACKNOWLEDGEMENT

All praises are due to 'Almighty' Allah, who enabled me to complete the piece of work for Ph.D. dissertation and without blessings of 'Almighty' Allah, it would not have been possible to successfully complete my degree.

I would like to express my warm appreciation and put on record my heartfelt gratitude to my esteemed principal supervisor, Associate Professor Dr Gurjeet Gill for his scholastic guidance, meticulous suggestions, constructive criticism, constant encouragement and untiring supervision which had enabled me to complete my research and degree successfully. Dr Gurjeet is one of the most positive people I have ever met, always welcoming me and his parental and friendly nature, and persistent inspiration always catalyzed me to solve all sort of problems in my everyday life. I would like to gratefully acknowledge the support of my supervisor Associate Professor Glenn McDonald, who has guided my research throughout my candidature with his vast and deep knowledge of the subject, assistance in developing the research project, conducting research trials and analysis of my data. As I prepared this dissertation both of my supervisors have spent many hours revising written material and editing my publications and their great efforts and assistance have been much appreciated but no appropriate words could convey my sublime obeisance to them.

I would like to express my sincere gratitude, indebtedness and profound appreciation to Dr. Peter Hayman, Principal Scientist, South Australian Research and Development Institute (SARDI) and Bronya M Alexander, Research Officer, SARDI for their assistance to develop and build the heat chambers and also assistance in imposing heat stress treatments in the field.

I feel privileged to express my sincere gratitude and thanks to Mr Chris Stone, Mr Ranjit Das, Durum Wheat Program, Waite Campus and Paul Ingram, SARDI for their support during field and glasshouse experiments. I am very grateful to Undergraduate Teaching Unit (Helen Brown, Toni Bennett), Waite Campus for their assistance with the analysis of plant samples for water soluble carbohydrate.

My thanks go to Dr Sudhir Yadav (Former Ph.D. Fellow, School of Agriculture, Food and Wine - AFW), Dr Samuel Kleemann (School of AFW), Mr Ben Fleet (School of AFW), Mr

Michael Zerner (SARDI) for their invaluable advice, technical assistance, support, help and friendship during my PhD tenure.

I would like to acknowledge the financial support from the Grains Research and Development Corporation (GRDC) in the form of Grains Industry Research Scholarship. I would like to acknowledge the financial, academic and technical support of the University of Adelaide in the form of Australian Postgraduate Award Scholarship at the beginning of my candidature and also assistance and technical support from their staff (Mrs Lisa Dansie, Mr Terry McKenzie and others).

Finally, special thanks and indebtedness are also due to my better half Mst Masuma Alam Shaheed for her personal help during experimentation, co-operation, encouragement and sacrificing familial time for successful completion of this work.