

# Low temperature adaption of wheat post head-emergence in northern Australia

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## ABSTRACT

Spring radiant frost is a problem in northern Australia for wheat crops at heading. Paradoxically, crops grown in warm sub-tropical climates are at greater risk than those in temperate regions due to faster development and rapid progression through to the susceptible reproductive stages. In sub-tropical northern Australia, spring radiant frosts occur frequently during the optimal flowering time. Planting is routinely delayed so crops are not heading during the maximum frost risk period. However, this results in a considerable loss of yield potential. Small increases in post head-emergence frost resistance would allow crops to flower earlier, significantly increasing yield potential, while maintaining an acceptable frost risk.

Frost damage of advanced crops is also important in Mediterranean and temperate growing regions of Australia, North America and Europe. For example in the USA, winter wheat can be damaged when warm conditions in early spring are followed by late frosts.

Research and screening for resistance to spring radiant frost has been undertaken in northern Australia for several decades. Our screening method allows frost resistance to be accurately assessed in isolation from frost escape mechanisms. The current trials have been conducted over 7 seasons at 2 sites in southern Queensland. A number of wheat genotypes with putative frost adaptation mechanisms exhibited no detectable advantage over standard Australian cultivars. Many current 'freezing' chambers are not suitable for screening in-head frost resistance. We are continuing field screening to identify sources of in-head frost resistance.

## INTRODUCTION

Post head-emergence spring radiative frost damage of winter cereals is a significant problem in Australia and several other regions including the Mediterranean and South America. The problem occurs in areas where the heat and drought of summer restrict the main growing season to the late winter and spring, where daytime temperatures are ideal for growth, but night temperatures can fall to damaging levels. Paradoxically, crops grown in warmer climates are at greater risk of injury due to faster development and rapid progression through to the susceptible reproductive stages (1). Growers routinely

delay planting to delay head emergence and, thus, minimise frost risk. Delayed heading exposes crops to increasing temperatures and dwindling water supplies late in the season, reducing yield potentials as heading is delayed.

The combined effect of direct frost damage, late flowering to minimise frost risk and terminal drought stress, represent a significant constraint to winter cereal production in the northern grains region of Australia. In the southern and western grains regions direct frost damage is also a significant problem. Therefore the development of wheat with enhanced frost adaptation would have a dramatic effect on wheat production in Australia. In the northern grains region, significant yield reductions are experienced due to (a) direct radiant frost damage, and (b) late planting to minimise frost risk. Yield losses due to direct frost damage of wheat in the northern region are estimated to be in the order of \$50 to \$100 million in an average year. In the northern region, dramatic increases in yield are observed when early flowering crops escape frost. The loss of yield potential as flowering is delayed coupled with the increasing likelihood of terminal drought stress represent even greater losses than those due to direct damage, but are necessary to maintain an acceptable frost risk.

Vegetative resistance does not confer in-head frost resistance. Many elite winter wheats are tolerant (LT50) to temperatures of  $-20^{\circ}\text{C}$  in the vegetative stages. However after head emergence wheat suffers severe damage at milder temperatures (plant minimum temperatures  $-5$  or  $-6^{\circ}\text{C}$ ). Unfortunately, this seems to be equally true for wheats of both winter and spring habit. For example, severe frost damage was observed in Canada in 2004 with "fall" frosting of advanced winter cereal crops (<http://www.abc.net.au/rural/wa/stories/s1200790.htm>), and again in 2007 with the frosting of advanced winter wheat in the United States of America. It has also been shown experimentally that post head-emergence frost resistance in winter habit wheat is little different to spring wheats (2).

In-head frost resistance has been a focus of investigation for more than a century (Farrer, W. 1900 in (3)). Yield gains have been made through better management of frost risk, particularly by optimising the combination of planting dates with varieties in the northern grains region. However, there has been little progress in finding true genetic in-head frost resistance. It is

difficult with current techniques to reliably detect differences of tolerance of  $< 0.8^{\circ}\text{C}$ . It is unlikely that differences of this magnitude would be of economic importance to growers or of practical use in a breeding program. In order to improve the efficiency of research and breeding, stringent testing of lines is required. We have developed rigorous testing methods that minimise the confounding effects of small differences in phenology and spatial differences in temperature.

## Defining Terms

Frost as defined by meteorologists does not necessarily result in damage to wheat. A ground frost is regarded to have occurred when the grass temperature falls to  $< 0^{\circ}\text{C}$  (4). Wheat post-heading can resist damage under mild ground frosts. As air temperatures within the crop canopy fall lower than  $-3.5^{\circ}\text{C}$  and plant temperature even lower, heading wheat can suffer damage.

Radiant frost occurs when still cold air, clear skies, and a dry atmosphere combine, allowing rapid radiation of heat to the night sky. Such weather patterns in northern Australia are typically associated with high atmospheric pressure systems. These radiant frosts are a particular problem in spring as crops develop to susceptible post heading stages.

The crop temperature experienced and recorded can vary widely due to differences in topography, micro-environment and recording method. In these studies minimum plant temperatures are measured using fine thermocouples and indicative air temperature measured with a minimum thermometer within the canopy. At mild subzero temperatures, the minimum temperature of the plants is typically ( $\sim 1\text{-}3^{\circ}\text{C}$  thermocouple) colder than canopy air temperatures which in turn is typically lower by  $\sim 2\text{-}4^{\circ}\text{C}$  than Stevenson Screen temperatures.

### *Components of Post-Heading Frost Adaption*

To clarify post-heading frost adaption it is useful to use a system similar to that outlined by Levitt (5) for drought. Under such a system frost adaption can be assessed in terms of frost escape and frost resistance. The latter can be further partitioned into freezing avoidance and freezing tolerance.

Using this framework, frost escape can be viewed as the evasion of frost by phenology. For example employing shorter or longer season wheat so heading occurs at a time outside the main frost risk period. Significant progress has been made in optimising planting times for varieties to maximise yield potential while minimising frost risk in northern Australia. The matching of “what to plant when and where” is integrated in decision support computer packages such as “Wheatman” (6).

Wheat may survive frost through one of two frost resistance strategies. Wheat plants have the ability to supercool to mild sub-zero temperatures without the formation of ice within the tissues. Freezing avoidance by supercooling allows the plant to survive freezing conditions by avoiding potentially damaging ice formation in tissues. In contrast to frost escape, with freezing avoidance the plant faces the challenge of frost but avoids ice formation. Alternatively, the ability of tissues to actually be frozen but survive would be described as freezing tolerance.

This system of defining frost adaption in terms of frost escape, freezing avoidance, and freezing tolerance provides a useful framework with which the physiological basis of potential adaption mechanisms can be discussed.

## METHODS

Trials were established over 7 years (commencing in 2000) to quantify levels of increased post heading emergence frost resistance in selected wheat lines. Screened material included CIMMYT synthetics, lines with potential adaptation and elite varieties. Potential adaptations included-

- morphological differences including awned/awnless, club head, “hairy” glumes and waxy cuticle types
- lines varying in levels of compatible solutes
- spring habit material with improved vegetative frost resistance derived from a winter type (TPZ\*\* spring type from a complex cross with Cheyenne)
- types with anecdotal or other potential adaption.

Test lines were compared to control varieties Kite and Hartog. Field trials were established at two sites the QDPI&F farm site at Kingsthorpe (15 km west of Toowoomba) and the QDPI&F Hermitage Research Station. These sites have been shown to consistently produce damaging radiant frosts between May and August. The two chosen sites routinely vary in minimum temperatures on a given night exposing plants to a wide range of frost intensities over a typical season. Trials were established with two or three planting times (April to June) and supplemented with artificial lighting (day length extended to 18h). Artificial lighting was supplied at the end of 5m rows. The intensity of artificial lighting reduced along the row resulting in a range of flowering times along each row. Serial plantings allowed material to be screened throughout the season when natural frosts occurred. Differences in the observed temperatures during any specific frost event between plants sown on different dates (7) prevented the comparisons of varieties between serial plantings. Variations in temperature across the trial were minimised where possible. Canopy structure was standardised by modifying seeding rates (dependant on germination rate) to generate a uniform establishment

and canopy. Guard rows were planted surrounding the trial to continue this standardised canopy. Plant minimum temperatures (at the top of the canopy) were recorded using “Tinytag” data loggers recording at five minute intervals. Canopy air temperature measurements were made using minimum thermometers within the upper canopy. Key to this method is the careful marking and monitoring of individual heads immediately following well-characterised frost events. On the day of a frost event individual heads are marked with spray paint. Care is taken to avoid heads that have been exposed to any previous frost events. With this screening method frost resistance can be accurately assessed in isolation from frost escape.

## RESULTS AND DISCUSSION

During the 7 years of trials, no wheat line tested showed a reproducible useful increase in frost resistance over the control varieties, Kite and Hartog. Severe universal damage was observed in all tested material at plant minimum temperatures less than  $-7^{\circ}\text{C}$ . This trend was observed for all frost events in all years at both field sites.

Barley, unlike wheat, when tested in similar trials often showed damage to varied numbers of individual florets or grains. Similar quantitative floret/grain damage was not routinely observed in tested wheat lines. Partial damage to wheat heads was more often associated with frosting before head emergence. In addition to damage of floral structures and grains, wheat commonly suffered damage to the stem. This stem damage, most prominent above the top node, resulted in the loss the head.

There have been a number of instances where wheat lines with putative in-head frost resistance have been identified opportunistically in yield trials or in oversimplified frost trials. To date, these lines have failed to produce a resistant variety. This may be due to very small differences in phenology resulting in frost escape. Alternatively, temperature differentials in the trials may vary the intensity of the frost experienced by particular lines. In order to improve the efficiency of research and breeding, stringent testing of lines is required. The method outlined in this paper minimises the confounding effects of frost escape and spatial differences in temperature. The number of lines rigorously screened remains low. Therefore as more material is screened there remains a possibility of identifying a source of increased frost resistance.

Using the system of defining frost adaption outlined in this paper it is possible to better understand potential mechanisms of frost resistance. Freezing tolerance has been extensively studied in winter wheats. Overwintering acclimated vegetative winter wheats are able to tolerate freezing of tissues. If similar freezing tolerance was observed post head-emergence, it may add to the frost resistance. Using infrared imaging post

heading wheat plants have been observed supercooling to mild sub-zero temperatures (2). Increased freezing avoidance by supercooling to lower temperatures would improve frost resistance. Preventing ice nucleation is important in maintaining supercooling. Therefore ice nucleation is being studied under field radiant frost conditions. In contrast to observations in the field, deep supercooling is routinely observed in artificial freezing chambers (8). Therefore studying frost resistance, particularly frost avoidance, in artificial freezing chambers becomes extremely difficult.

## CONCLUSIONS

Spring radiant frost, post head emergence, is a major limitation to increasing wheat yields in northern cropping region of Australia. However no tested line to date has shown a useful level of increased frost resistance. The number of lines screened remains low. Future screening needs to be undertaken with a rigorous method that minimises frost escapes. Artificial freezing chambers that have been examined to date allow deep supercooling and are therefore not suitable for screening.

## REFERENCES

1. Single, W. (1984) Frost Injury and the Physiology of the Wheat Plant. The Journal of the Australian Institute of Agricultural Science, Vol. 51, pp. 128-134.
2. Fuller, M. P., Fuller, A. M., Kaniouras, S. Christopher, J., Fredericks, T. (2007) The freezing characteristics of wheat at ear emergence. European Journal of Agronomy. Vol. 26, pp. 435-441.
3. Single, W. (1964) Studies on frost injury to wheat. Australian Journal of Agricultural Research, Vol 15, pp. 869-875.
4. Foley, J. C. (1945) Frost in the Australian region. Commonwealth Meteorological Bureau, Bulletin No. 32. J. J. Gourley, Government Printers, Melbourne.
5. Levitt, J. (1980) Responses of plants to environmental stresses. 2<sup>nd</sup> Edn, Vol 2, New York Academic Press.
6. Woodruff, D. (1992) “Wheatman” a decision support system for wheat management I subtropical Australia. Australian Journal of Agricultural Research, vol 43, pp. 1483-1499.
7. Frederiks, T. M., Christopher, J. T. and Borrell, A. K. (2004) Investigation of post head-emergence frost resistance in several CIMMYT synthetic and Queensland wheats. 4<sup>th</sup> International Crop Science Congress. Brisbane, Australia, 26 September – 1 October 2004.
8. Frederiks, T. M., Christopher, J. T. and Borrell, A. K. (2004) Simulation of radiant frost- as pertaining to winter cereals post head emergence. International Controlled Environment Meeting. Brisbane, Australia, 14-17<sup>th</sup> March 2004.