Regional Frost - Calibration of Frost Chamber to encompass all Australian conditions

Summary

Spring radiation frost is a serious problem for the Australian grains industry. This project has developed frost-chamber testing protocols that use ice nucleators and infra-red video thermography (IRVT) to predict frost resistance in the field. These protocols open the way to use frost-chamber tests to differentiate lines and varieties of wheat and barley for frost susceptibility in different grain growing regions and have the potential to accelerate breeding of frost resistant wheat and barley varieties. This will benefit the grains industry and individual growers by preventing loss of millions of dollars each year due to frost damage and delayed planting. Three publications are in preparation.

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Conclusions

1. In experiments in South Australia (SA), varieties that were grown either in pots in the field at Loxton (then transported back to Adelaide and tested as soon as possible after a frost event) or in the Australian Genome Research Facility’s (AGRF) controlled environment were most robust and could most readily be differentiated for frost resistance in the AGRF chamber. In experiments at the University of Southern Queensland (USQ), plants grown in the glasshouse during winter and early spring could be readily differentiated for frost resistance in the USQ frost cabinets.

2. Frost resistance determined in either of these locations resembled described trends in the field, but sometimes not exactly. For example, in the AGRF chamber, DMS130 performed better than or as well as WI3806 and both tested more frost tolerant than Stirling, while in the field at Loxton WI3806 was about the same as Stirling and DMS130 and WI3806 performed better than Stirling or WI3806. At USQ, DMS130 was more frost tolerant than Stirling and both barleys (DMS130 and Stirling) were more frost tolerant than the wheat variety Young. Icarda 70, agreed as frost susceptible by SA and Queensland (QLD) workers, performed just as well as DMS130. Statistical analysis of frost-induced sterility in these National Frost Trial wheats and barleys failed to reveal any significant differences among wheats or among barleys (pers. comm. Jack Cristopher, Michael Laws), so field observations are the only basis for these comparisons.

3. The development of a consistently effective ice nucleation and frosting method using Snomax is an important contribution to available technology for testing frost tolerance of wheat and barley in chambers and will enable plants to be subjected to chamber conditions that more closely resemble a field environment. Snomax was first used by Dr Joan Vickers as an ice nucleator for the freezing of plants during experiments with Professor Mick Fuller in 2006.

4. The method developed at USQ to use an infra-red (IR) video camera to observe freezing exotherms during frost trials in chambers has been very successful. Unlike in the field, where success is dependent upon the occurrence of a frost, temperatures can be lowered at will, under desired sets of conditions. These experiments have provided much information on exotherm characteristics with and without Snomax and on the roles of ice nucleation and freezing in plant damage, although resolution of the images obtained through the two IR transparent windows needs to be improved.

5. Frost profiles using Snomax work well to test relative frost tolerances at early grain fill stage. Frosts during this growth stage have caused extensive damage in the field e.g. October 2009 in western New South Wales (NSW). More work is needed to test frost-sensitivity of wheat and barley varieties at different growth stages under different environmental conditions.

Recommendations

1. Further development and testing of frosting methods using Snomax should include trials using different application methods, including a built-in mister with variable droplet sizes to achieve a more uniform distribution of droplets.

2. More repetitions of these experiments are desirable. Numbers of varieties tested were limited in order to maximise the opportunity for repetitions and another year of tests to ensure repeatability is recommended.

3. The Cedip infra-red video camera kindly lent by Drs Jack Christopher and Troy Fredericks is a valuable asset to our attempts to elucidate the role of freezing (as opposed to cold) in plant damage. Much has been learned in this year’s
series of experiments but there are still questions about the details of plant damage during the freezing process in the presence of an ice nucleator. Stem exotherms were not observed in all experiments. More experiments that focus on stem damage are needed. Further investigation using infra-red video thermography (IRVT) is needed to determine whether or not freezing is occurring, particularly with Snomax. Conductivities indicated that freezing did not always occur despite plant damage.

4. Image resolution through the IR transparent windows could be improved, possibly by moving the windows closer together. Two windows are needed to prevent condensation. Further engineering is desirable, for example, a method to enable continuous evacuation of the space between the windows, a mounting method that does not require duct tape and an air-locked, hinged door that can be opened to replace desiccant between the windows.

5. Further engineering on the USQ frost chambers is needed to improve temperature control. The negative feedback should be moved from the base of the chamber to the plant canopy.

6. There is a substantial temperature gradient in the AGRF Adelaide chamber that causes the right side to be cooler than the left side during a frost run. In some cases, results were so different that groups of plants on either side had to be treated as separate experiments. An engineering solution to this problem may be possible.

7. A much higher level of funding is required than was available in this project. Achievement of milestones was possible due to the generous provision of a controlled environment space and accommodation by Dr John Stephen and very careful budgeting. In addition, Dr Vickers worked for more than half of the year without being paid, working full time rather than half time from July to December in both years of the project.

Outcomes

The expected outcome of the project is acceleration of the breeding of frost resistant wheat and barley varieties by providing frost chamber testing protocols that differentiate varieties for different grain growing regions using on-call tests that predict frost resistance in the field. The grains industry and individual growers will benefit by prevention of loss of millions of dollars each year due to frost damage and delayed planting.

Economic outcomes: prevention of loss of millions of dollars in direct and indirect costs.

Environmental outcomes: decreased risk of crop loss, possibly better weed control due to less plant death.

Social outcomes: benefits to local communities due to increased farm income.

Achievements/Benefits

Spring radiation frost is a serious problem for the Australian grains industry. Direct losses can cause a yield reduction of 10-100% of the crop, as occurs in Queensland where minimum temperatures are lower. Indirect losses result from growers delaying planting to avoid frosts. Planting later increases the likelihood of heads flowering in warmer conditions. This reduces grain fill, causing 1-1.5% yield loss for each day that flowering is delayed past the optimal time in early August. This loss is in addition to losses from direct frost damage and can be as high as 50%. Million dollar losses due to frost are reported in most years in grain growing regions of Australia. Some wheat and barley varieties behave differently in different regions and there is a need for development of frost chamber protocols that cause the same degree of frost damage as occurs in the field, so frost chamber testing differentiates between varieties in the same way as a field trial. Frost chamber testing has the potential to greatly accelerate the process of breeding for frost resistant wheat and barley varieties. Field testing is unreliable because the occurrence of a frost cannot be guaranteed.

Major achievements

1. Determination of plant growth conditions for successful testing in the frost chamber.

Plants were grown in the field and in pots in the South Australian Research and Development Institute (SARDI) glasshouse at Loxton, SA, and in the AGRF controlled environment (CE) facility in Adelaide then tested for frost tolerance in the AGRF frost chamber. The most vigorous plants were grown at Loxton in buried pots. This technique was used because digging up and transporting plants from field-grown crops creates stress that decreases frost tolerance. Some of the best discriminating trials in the AGRF chamber were performed on plants grown in CE conditions mimicking SA winter conditions. DMS130 performed particularly well compared to other varieties when grown under cool conditions in the CE facility. The SARDI glasshouse was a poor growth environment due to lack of user control over temperature and light cycle. Good discrimination which mirrored the order of resistance observed in the AGRF chamber and trends in the field for DMS130 and Stirling barleys and Young...
wheat was achieved in the USQ frost cabinets with plants grown in the glasshouse during the winter/spring growing season.

2. Optimisation of the Snomax ice nucleation method to distinguish varieties in frost chamber tests.

Trials were carried out at varying temperatures using Snomax for ice nucleation in the AGRF chamber and in USQ frost cabinets for IRVT observations. Snomax is a very strong ice nucleator that mimics frosting in the field where natural ice nucleators are present and ice crystals form on plants. With Snomax, plant damage progressed from no damage to total plant death over a narrow range of temperatures between -3.0°C and -4.5°C. These temperatures usually cause little to no damage in wheat and almost no damage in barley under supercooling conditions in frost chamber trials. The best temperatures for varietal discrimination were -3.5°C in the AGRF chamber and slightly higher in the USQ cabinets, with differentiation failing as temperatures decreased, a result reminiscent of the poor performance of the variety Haruna Nigo in the more severe frosts of Kingsthorpe, QLD, compared to its relative frost tolerance at Loxton, SA. Spraying of Snomax was most effective when performed to run-off at 0°C in the AGRF chamber and 2°C in USQ cabinets. Plants at early grain fill stages were particularly susceptible to ice nucleator initiated freezing. Freezing at this stage causes significant losses to the industry.

3. Use of infrared video thermography (IRVT) to enhance our understanding of freezing in wheat and barley and hence the usefulness of frost chamber testing methods.

Fifteen trials were carried out in 2010 on wheat plants (Wyalkatchem, Young, Kite, Halberd and Cranbrook) using supercooling and Snomax protocols. Freezing patterns and exotherm characteristics were very different in the two types of experiment. In supercooling experiments, exotherms were usually initiated at the base of tillers, rapidly invading the entire tiller, leaves and head. With Snomax, exotherms were initiated at Snomax droplets then radiated locally into surrounding tissue and areas where exotherms had occurred, gradually coalescing to cause tissue death. Stem exotherms, which occurred at lower temperatures, caused total plant death. Amplitudes of exotherms were much greater in supercooling experiments, up to 4.5°C (less when initiated at higher sub-zero temperatures). Conduction velocities were highest in stems, lower in leaves, where they tended to first travel up veins then spread more slowly through smaller lateral vessels, and slowest in heads and awns.

Characteristic exotherm shapes occurred in different tissues. Exotherms initiated by Snomax were less than 2°C in amplitude. In supercooling experiments, temperatures down to -16°C were necessary to freeze all plants and sterility was 100% in heads where exotherms were observed. Heads that escaped freezing were apparently undamaged. In contrast, intact florets were found in heads that had experienced localized exotherms. Snomax-initiated freezing in frost chambers probably more resembles freezing in the field than does the explosive freezing pattern that accompanies supercooling.

Benefits

Development of these new testing protocols provides the opportunity for new and current varieties to be grown in a controlled environment facility and tested for potential frost resistance in the AGRF (or similar) frost chamber at any time of year. More testing should be carried out before establishing a commercial testing program. There is the potential to greatly accelerate selection of germplasm for frost resistance, leading to a large yield increase for wheat and barley and hence improved profitability.

Additional information

Manuscripts in preparation on results of testing of wheat and barley for frost tolerance, characteristics of exotherms observed during Snomax and supercooling frost profiles, and comparative aspects of climate change and plant environments in the three major grain growing areas of Australia.