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Project Code	
Project Type	

FINAL REPORT 2023

Final reports must be submitted using the online application form at www.sagit.com.au with this Word document attached ***within two months*** after the completion of the Project Term.

PROJECT CODE	MHR121
PROJECT TITLE	
Frost Learning Centre for farmers, advisers and researchers	

PROJECT DURATION						
Project start date	**1/07/2021**					
Project end date	**30/06/2023**					
SAGIT Funding	2021/2022		2022/2023		(year)	

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PROJECT REPORT: *Please provide a clear description for each of the following:*

Executive Summary (200 words maximum)

The project has shown there are methods and practices to avoid, tolerate and mitigate the impact of frost. It has also increased the knowledge of farmers and advisers as to how frost occurs, how and why frost risk management zones are important, the spatial variability of frost and identification of frost damage in crops. Ice nucleating bacteria have been identified as an important contributor to freezing and the distribution in the plant identified as a result of the project. Practices that enhance ice nucleating activity or, conversely, reduce uptake of, or provide effective competition to, INB have been investigated. Dual or multipurpose cereal crops, which can be harvested for grain, grazed at or near maturity or cut for hay have been identified for grain yield. The impact of plant density, nitrogen nutrition, desiccation have been investigated. The research results suggest high nitrogen nutrition, in combination with seeding rate, has not resulted in increased frost damage. The project aim to build on previously conducted and initiate innovative research at one site where individual research outcomes could be compared, extension activities could be focused and engagement of frost affected farmers obtained has been successful. Trials and discussions to assist advisers in their knowledge of frost and strategies to reduce the financial impact, to question and promote discussion of appropriate research methodology, to provide an opportunity for young researchers to gain insight and experience in frost research, and to test new innovations and technology applicable to frost.

Project objectives

The aim of the project was to provide information for growers to identify frost impacts on their properties, to understand how frost occurs, to research frost avoidance strategies that can be implemented. A key component of avoidance is to provide phenology information to enable more informed cereal variety choices for different frost risk zones. Species and variety tolerance were identified as important tools and the project aim was to decrease losses by growing very vulnerable crops. Dual purpose crops provide opportunity to cut, graze or cut for hay dependent on frost damage and economics in frost prone areas. The adoption of dual purpose wheat was a particular aim. Having an intervention to delay phenology. Understanding the role of INB in INA and how to reduce the risk of high INA

Overall Performance

The project achieved the objective of increasing the awareness of frost, providing assistance in identifying frost damage and providing alternatives to reduce risk while not limiting the profitable options where frosts do not have any impact.

The project outcomes also provide valuable insights into the methodology required for frost research and where future efforts should be directed.

The following personnel participated in the project:

Mick Faulkner (Agrilink): Research, trial management, project coordination and extension
Ben Smith (Agrilink): Trial management, coordination and extension, survey development
Jarred Tilley (MNHRZ): Event and extension coordination, project management
Deb Baum (MNHRZ): Extension activities
Penny Roberts (SARDI): Collaboration with pulse intercropping and spring seeding of pulses

Difficulties encountered included having sufficient resources to conduct detailed dissemination of heads to determine grain viability. Repeated frost occurrence requires removing and relocating exclusion devices on a regular basis (ideally after each frost event). It is not possible to deploy the required number of shelters in a required timeframe, nor is it possible to maintain the number of plots required to be available without introducing spatial variability. Trial designs are difficult for frost research as many trials require that there be minimal gaps surrounding individual plots. Taking measurements and obtaining harvest data means that there must be interplot gaps and removal of material at the end of ranges. Plots need to be large to gather data of sufficient quality but plot size directly affects the degree of spatial variability, necessitating smaller plots in practice.

Thermography has the potential to capture freezing of plants most reliably but a number of expensive cameras are required. Video or high frequency imagery is required which must be set at an appropriate focal distance, be focused on the right area and be of sufficient pixel size and clarity to be of use. The project was not able to achieve the integrity of imagery required with available

imaging options. Manually derived thermal imagery is limited to a time period before sunrise begins to heat the surface. There is a limit to obtaining this imagery.
Destructive sampling is limited in its application as grain yield is also required from the same plots. Increasing plot length to provide for more destructive samples results in greater spatial variability.
By its very nature the choice of site for frost research is problematic. There needs to be an extremely high chance of receiving frost damage but that increased chance usually means that frequent frosts are experienced or more frosts produce damage and it is not possible to attribute damage to a single event. Choosing a location that has less frost, in the hope that one occurs at the right time that results in damage, might actually mean that no frosts actually occur and no results are therefore obtained.
Using frost chambers has not replicated frosts in the field and frost inclusion mechanisms, such as dry ice descending enclosures also have not been shown to be reliable.

KEY PERFORMANCE INDICATORS (KPI)

KPI	Achieved	If not achieved, please state reason.
2021 Frost learning centre established	Yes x	
Establish phenology trial	Yes x	
Establish dual purpose trial	Yes x	
Establish nitrogen trial	Yes x	
Establish biomass trial	Yes x	
Establish stubble trial	Yes x	
Establish delay & reset trial	Yes x	
Establish legume demonstration	Yes x	
Year 1 trials completed	Yes x	
1 frost learning day for researchers	Yes x	
2 frost field days for farmers, advisers,consultants	Yes x	
Yr 1 Harvest data collected and disseminated	Yes x	
2022 Frost learning centre established	Yes x	
Yr 2 trials completed	Yes x	
2 frost learning days for research & extension	Yes x	
2 frost field days for farmers, agronomists, advisers	Yes x	
Conduct GRDC extension activities and field days	Yes x	
Harvest data collected, interpreted and extended to consultants, researchers, project partners & MNHRZ group members	Yes x	
Final Report	Yes x	

TECHNICAL INFORMATION (Not to exceed **three** pages)

Frost damage can be due to 1)chilling, where plant parts are damaged without freezing occurring, or 2)freezing, where ice is formed within and between cells. This project has placed emphasis on freezing damage. However, the process of freezing is complicated by the fact that cell contents contain solutes that confer a degree of antifreeze properties. The point of freezing is in response to nucleation, on which ice forms. Nucleation is predominantly caused by naturally occurring bacteria that reside in intercellular spaces. The actual temperature at which ice forms is therefore influenced by the concentration of ice nucleating bacteria and the ability of cells to expand without rupturing. Damage is also influenced by the degree of damage to cell walls and if this damage is repairable.

The temperature at which these processes occurs is at the cellular level. The relationship between cellular temperature and air temperature surrounding sensitive plant tissue is not determined in field experiments and assumptions are often made and algorithms developed that attempt to correlate air and cellular temperature. There is no strong evidence that the correlations are correct. The further the temperature recording device is from the plant being studied, the weaker the correlation. The project used a limited amount of thermography to investigate plant temperature in some trials.

There were a significant number of 'frost events' as defined by the BOM definition of less than 2.2℃ in a Stevenson screen at 1.2m. There was no definitive method available in this project to determine which events actually resulted in ice formation and cell disruption (frost damage).

In 2021 there were 67 events below 2.2℃ with 15 potentially damage causing events between September 1 and November 10. Of these, there were regular frost events (9) between Sept 1 & 21, 4 events (one particularly severe) from Oct 6-12 and 3 at the end of October and start of November. Thermography indicated that temperatures much lower than air temperature were evident on plant surfaces during frost events.

In 2022 there were 63 events below 2.2℃ with 16 potentially damaging events from September 1 to November 10. A verfy cold event occurred occurred on Oct 10 but resultant frost damage was minimal. Where frost damaged spikelets were identified there appeared to be adequate compensation of the remainder of the spike or spikes of adjacent, or later order, tillers. The result was no yield loss. (*Appendix 1*)

A problem with frost research is that it usually isn't possible to determine which frost actually caused damage when there are more than one. The use of multiple frost exclusion structures rotated between sites is required for this research. The project used a limited number of passive exclusion structures for some trials.

One project aim was to determine if the main ice nucleating bacteria, *pseudomonas syringae* (INB) was present in plants at the FLC site, their distribution in the plant and their capacity to cause ice nucleation (INA). A bioassay developed by scientists at DPIRD, WA has been used to determine INA and field sampling techniques consistent with best practice adopted in the project.

INA assay results indicate INB is present in large quantities in project samples. Distribution differs slightly compared to WA samples with higher concentrations present on, and in, flag leaves. Concentrations on older senescing, leaves is consistent with samples in WA (personal communication A Bakuma). Previous research in WA (Biddulph) indicated nucleation occurred toward the base of wheat plants due to high concentration of INB in senescing or senesced leaves. Project results from the FLC indicate INA is greater at flag leaf level in SA but also significant due to older leaves. (*Appendix 2* & *Appendix 3*)

Reducing the impact of frost can be achieved by avoiding having plants at susceptible stages when damaging frosts occur. This is known as an avoidance strategy. It is generally believed the most severe frost losses occur during anthesis but that is challenged, both by farmers and research outcomes. However, using anthesis as a benchmark for timing has appeal, as it is a stage easily identified and reasonably well modelled by APSIM and other tools. In general terms, avoidance usually means delaying anthesis until after the last damaging frost occurs. Occasionally it can also be achieved by very early maturity whereby grain filling is largely completed by the time frosts occur in spring. We were not able to achieve the latter outcome with the project as early maturity inevitably resulted in the greatest frost damage.

Barley is known to have slightly more tolerance to frost than wheat but the narrow phenology range of contemporary varieties meant they were all early maturing when sown on April 17. Comparative maturity was also fairly early with May 17 seeding. It would appear that all barley varieties in the project were too early maturing in high frost risk areas when farmers prefer to seed in April and May. Photoperiod or vernalisation responsive barley varieties are required for early sowing in highly frost prone areas. (*Appendix* 4).

Changing maturity can be achieved by altering seeding date, growing varieties with different maturity or intervening a growing crop with defoliation, usually by grazing, or manipulation using plant growth regulators.

Defoliation has two pathways: the first is one or more treatments prior to Zadok's growth stage 30 in order to delay maturity (Delay). The second is to remove apical dominance (Reset) so as to initiate new tillers from the base of the plant or allow very late order tillers to produce the main heads (*Appendix* 5). Results from the project indicate reducing apical dominance by defoliation is difficult to achieve in practice. Defoliation, instead of removing apical dominance, simply transferred it to the next most advanced apex on the plant. Therefore, new tiller initiation did not occur unless all heads on all tillers were removed. This correlates with previous research (Faulkner, 2014) which indicated new tiller production did not occur until frost resulted in the death of all heads on wheat, which coincided with the most advanced tiller being at GS39 or later. The conclusion from the project is that reset by mechanical defoliation is not a tactic that can be adopted successfully in the main wheat growing areas. Its successful adoption is restricted to very long growing seasons where sufficient soil moisture is available and there is low heat incidence, after the 'frost season' has passed.

The delay treatment can be successfully implemented. Yield due to this intervention can sometimes be positive, especially with barley. Recovery to grain yield, in the absence of frost is influenced by biomass recovery, time to anthesis, water and nitrogen resources. When frosts occur, previously the positive yield response was thought to be due to phenology change, but this project indicates the reduction of INB may also play a role. It is possible that the application of specific plant hormones can initiate tillers but it is not known if the influence of INB is reduced as occurs with grazing or simulated grazing.

Both interventions result in removing large quantities of nitrogen. Nitrogen can be a limiting factor in achieving sufficient biomass and leaf area for grain production.

Another method examined in the project to avoid frost at critical times is to create diversity of growth stages in the field population. 2021 results indicate the highest yielding wheat variety in a red zone (high frost risk) is not the same as the variety in the green zone. Mixing and intercropping of varieties, with different maturity can achieve this goal. The project results in 2021 indicated no difference in response between intercropping and mixing of cereals resulting in intercropping being removed from the 2022 research. Mixing of cereals is one of the simple, easily adopted methods to create diversity with positive results from the project. (*Appendix* 6,7)

Frost tolerance is a desirable characteristic to reduce loss. There are differences between species. The project identified, or confirmed, that oats are more tolerant to freezing damage than wheat or barley. Literature, research and field reports suggest barley is more tolerant to frost than wheat, but this project was unable to validate that finding. Barley was severely damaged in 2021, which may be a response to early maturity rather than lower tolerance per se.

Frost damage was determined in 2021 as no damaging frosts occurred in 2022. One outcome of the 2022 research proved that the productive potential of highly frost prone sites is as great as non frost prone in the absence of frost.

2021 research showed oats were more tolerant to frost compared to wheat and barley. In contrast to previous research however there was no evidence of stem frost in oats.

Tolerance between species can be negated by phenology, meaning an advantage might be lost if earlier maturity exposes crops to a larger number, or more severe frost events.

Mitigating the impact of frost is an important management option. Mitigation options include practices that reduce INA, and by inference, INB. These practices can also influence tolerance or avoidance and there is considerable crossover. High stubble resulted in lower temperature at 25cm above ground level during vegetative stages but the impact became negligible at crop canopy height later in plant development. It is reasonable to assume that the relative radiation heat loss from the canopy becomes more important than soil or stubble as the crop develops the canopy. Stubble can contain high levels of INB resulting in significant INA. It is thought high INB in stubble is easily transferred to lower leaves of crop resulting in high INA and freezing damage initially towards the base of the plant (Biddulph pers comm). The very cold temperature produced in the bottom 25cm of the plant could result in higher levels of INB earlier in the season, predisposing plants to repeated freezing damage and greater susceptibility in spring. It was not possible to differentiate between simple temperature effects and INA effects in this project. (*Appendix* 8,9).

Cutting frosted crop for hay is a common practice in southern Australia. However, this practice relies on market availability and acceptance. There is a limited on-farm requirement for cereal hay, while domestic dairy and beef industries and international livestock enterprises, through the export fodder industry, have a high and constant demand for quality hay. Visual and physical characteristics are relatively unimportant for the total mixed ration market and quality is somewhat less important, as nutritional needs can be supplied with other components. However, when fed ad lib or intact, the presence of awns is a priority consideration. Both domestic and export markets have a strong preference for awnlessness, or reduced awns. High quality export fodder is based on oats or awnless wheat or barley. This project compared the grain yield of awnless wheat and barley with contemporary varieties so as to allow growers to cut for hay, if frosted, or retain as a grain crop if there was no frost damage.

There may be a compromise in growing a dual purpose wheat in order to produce sufficient hay, meaning a lower HI compared to high yielding contemporary varieties. Varietal performance is summarized in *Appendix* 10.

This project indicated there was no impact of gibberellic acid or gibberellic acid inhibitors, trinexapac ethyl and paclobutrazole, on frost damage. (*Appendix* 11)

Biomass production varies with location and delaying seeding in cold areas to avoid frost can result in low winter productivity, followed by high levels of spring growth if soil water conditions allow. Delaying seeding to avoid frost may have negative consequences for total biomass production. Earlier sowing with photoperiod or vernalization responsive varieties might increase winter production while delaying maturity more effectively than late sowing of temperature sensitive varieties. (*Appendix* 12)

Increasing nitrogen rate or seeding rate did not result in greater frost damage in 2021, and there were no damaging frosts in 2022. The results, however are influenced by substantial late season rain in 2021. (*Appendix* 13). Plant surface temperature was lower as canopy size increased during a frost event on October 11.

The project investigated the role of spring sown chickpeas (in conjunction with SARDI) and SHO safflower as valuable frost avoidance strategies. Both show promise.

Extension activities have resulted in increased awareness of frost damage and strategies to reduce financial loss. Participant end of project survey indicates many advisers and farmers have increased their knowledge and adopted practices to reduce financial loss. Field days, crop walks and workshops were conducted as part of the project. (*Appendix* 15)

Identification of frost damage was an additional outcome of the project. Participants were trained in assessing frost damage.

The project investigator presented at GRDC events in Adelaide, Bendigo and Bordertown. Since the conclusion of the project presentations have also been made to the Central Ag group for the GRDC RiskWi$e project and the launch of the project for the MNHRZ group.

CONCLUSIONS REACHED &/OR DISCOVERIES MADE
The project has resulted in: Affirmation that a dedicated frost research and extension project at an appropriate field site makes a valuable contribution to reduce frost loss, ensure knowledge is gained and frost research is conducted with rigor and methodologies Extension of current frost knowledge to advisers and farmers Knowledge of the degree and extent of sub zero temperatures that could cause frost damage at the Frost Learning Centre site Identification of practices to reduce risk, adoption of grain and hay oats compared to wheat, sowing long season varieties early, mixing of varieties to provide variability in growth stages, dual purpose cereals, profitable pasture options in cold environments, The results are consistent with the frost zoning approach developed and promoted by previous research (Faulkner). Understanding zoning and how to create zones, what management practices can be implemented in each zone, understanding of INA and a platform for future research The principal ice nucleating bacteria, pseudomonas syringae, was present and its distribution determined in plants. Methods to reduce or minimize p. syringae population or activity could reduce losses to frost by reducing ice nucleation activity (INA).

INTELLECTUAL PROPERTY
There is an opportunity to use thermography to determine 1. The spatial and temporal extent of freezing 2. Plant and treatment response

APPLICATION / COMMUNICATION OF RESULTS
The project outcomes main communication would be: • Ensure farmers have created long term frost zones consistent with Red (high financial loss), Green (no financial loss) and Amber (variable loss between seasons). • Align outcomes and strategies resulting from the project to the zones. An example is the highest yielding variety of wheat in a green zone is not the highest yielding variety in a red zone. Choosing the variety for the red zone implies knowing when the last damaging frost will occur. If that is known then separate varieties for each zone is an appropriate tactic. If it is unknown then the project indicates a varietal mix is a valid choice. • The timing of frost are difficult to predict. There can be a compromise between trying to avoid frost damage by later maturity and the onset of hot conditions and drying soils. In some circumstances growing a variety with slightly later maturity is a viable option. Delaying seeding is a tactic widely used but has a downside due to heat and dry in some regions and low biomass production in winter in others. Low biomass production can be a problem in cold environments. Early sowing with vernalization or photoperiod dominant phenology is another option. • Where hay market exists, growing awnless dual purpose wheat or dual purpose oats are appropriate as they can be harvested for grain or cut for hay. The final choice can be dependent on frost damage. No barley varieties are awnless. Hooded varieties in the project do not have have sufficient grain yield to be classified as dual purpose. • The role of ice nucleating bacteria needs to be further explored and tactics to compete with, reduce the proliferation or eliminate *pseudomonas syringae* could be

explored. Investigation of practices that influence the amount or activity of INB could reduce yield loss.

- Delaying maturity by grazing or some other physical intervention can reduce frost loss. Resettting phenology is less easily adopted and less likely to succeed with physical intervention.
- Identification of frost damage

POSSIBLE FUTURE WORK

The application of specific PGR's requires further evaluation.

Further work is required to investigate the impact of nitrogen nutrition, plant density and canopy on frost damage in a range of seasonal finishes.

Using stubble free of INB could be beneficial in future research.

Using thermography is considered necessary to determine when and how plants freeze in field experiments and to monitor treatment efefcts

The spatial variability in temperature and frost damage requires investigation to assist research validity

The role and proliferation of ice nucleating bacteria in frost requires further work

Suppression of INB or INA is an important area of future research. Isolating the effect of INA from other plant responses (ie cell strength, turgidity etc) holds promise. Assessment of farm practices, genetic solutions and product applications that contribute to freezing suppression, or conversely, make frost damage more severe continue to be important. A future project would investigate both INA and plant response.

The role of stubble and stubble management remains an important area of research.

Crop species and sowing times to avoid frost are valid research areas.

The role of photoperiod and vernalization driven phenology as am avoidance mechanism requires continued research and local validation of phenology is important to assist growers with varietal choice and sowing date. The current phenology trials should continue.

The role and selection of dual purpose crops for hay or grain remain an underfunded research area. While the advice is often to cut frost affected crop for hay, that tactic fails if there is insufficient biomass or the product has low demand or cant meet animal nutrition needs.

Investigation of frost management options for canola and pulses (including, and in addition to, the intercropping and late sowing research being conducted by SARDI).

Quantitative assessment of frost damage by machine learning or imaging technology is required for future work