Future issues with breeding for disease resistance in Australia – a vision

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Australian barley crops are affected by a range of leaf and root diseases. Diseases constitute a significant limitation to sustainable barley production. Reducing impacts from diseases is important for reliable production of high quality barley. Some diseases are prevalent around Australia whereas others are of regional significance (Table 1). The lack of resistance in major varieties grown in Australia to diseases like scald, net blotches, leaf rust and powdery mildew (Table 2) can impact on yield and grain quality mainly through a reduction in grain size. Reduced grain yields and low malting quality reduce returns to growers and affect domestic and export marketability. Improvements are sought through the development of varieties with adequate levels of resistance to the range of important biotic stresses. A major objective in barley breeding programs around Australia is to develop varieties with improved combinations of disease resistances while maintaining or improving yield, quality and other agronomic traits.

Table 1: Prevalence of leaf and root diseases in barley growing regions of Australia

Diseases	**West**	**South**	**North**
Powdery mildew	Major	Major	Major
Net type net blotch	Major	Minor	Major
Spot type net blotch	Major	Major	Major
Leaf rust	Major	Major	Moderate
Scald	Major	Major	Minor
Barley Yellow Dwarf Virus	Moderate	Moderate	Minor
Loose smut	Moderate	Minor	Minor
Cereal cyst nematode	Minor	Major	-
RLN (*P. neglectus)*	Moderate	Moderate	Minor
RLN (*P. thornei)*	Minor	Minor	Moderate
Common root rot	Minor	Moderate	Moderate
Crown rot	Minor	Minor	Major
Spot blotch	-	-	Moderate
Stem rust	-	-	Moderate
Barley grass stripe rust	Minor	Minor	Minor
Stripe rust	Exotic	Exotic	Exotic

Disease threats are ubiquitous, but epidemics are variable in incidence and severity across regions and seasons. An integrated approach to disease control is recommended, yet genetic resistance underpins effective management strategies in Australian production systems. Current and future issues affecting breeding for disease resistance are addressed below to maintain sustainable barley production in Australia.

Fungicides

Fungicide use in the Australian barley industry has changed in response to disease control need and price/return opportunity. Traditional use of seed dressings is being cost-effectively supplemented with

foliar fungicide application (Jayasena *et.al.* 2002, 2006). This has enabled farmers to manage disease risks in productive high quality varieties such as Franklin, Gairdner, Baudin and Hamelin. However, fungicides add to costs of production and complexity of crop management decisions, requiring due care to ensure that disease control practice conforms to sustainable and safe use strategies From a marketing perspective, it is highly desirable that the use of chemicals be limited to the minimum to maintain crop hygiene and through breeding strategies.

Table 2: Response of barley varieties to major leaf diseases in Australia, showing disease responses across commercial varieties. **

Variety	Scald	Net type NB	Spot type NB	Powdery mildew	Leaf rust
Barque	MR*	S	MR	MR	S
Baudin	I	MS	S	VS	VS
Buloke	MS	MR - MS	MS	R	S
Flagship	MS	MR	MR - MS	MS	S
Gairdner	I	MR - I	S	S	S
Grimmett	VS	S	S	S	S
Grout	VS	R	S	R	S
Hamelin	S	MS	S	S	S
Harrington	S	S	I - S	I - S	S
Molloy	S	MS	MS	I	S
Schooner	MS	MR	MS	S	S
Skiff	S	R - S	S	I - VS	S
Stirling	S	S	S	VS	S
Sloop	S	MR	S	I - S	S
Tallon	S	S	S	R	S
Vlamingh	MR	MR	S	S	S

*R = Resistant; MR = Moderately resistant; I = Intermediate; MS = Moderately susceptible; S = Susceptible; VS = Very susceptible.
** Some regional variation can exist in varieties to disease responses.

Breeding objectives addressing changing disease scenarios

Disease epidemics vary across regions and over years and are difficult to forecast. Spot type net blotch was a minor disease in southern Australia until the mid 1990s. In Western Australia in the last 5 to 10 years it has spread from central and northern areas of the WA wheat belt to the south coastal region where it is frequently epidemic (Jayasena *et.al.* 2007). Recent pathogen virulence studies suggest that isolates virulent on Stirling and Herta have been found that require identification of diverse resistant sources for utilization in the breeding program.

Similarly, barley leaf rust was a minor disease in Western Australia when virulence for leaf rust resistance gene *Rph12* (pathotype 5610P+) was detected in Franklin barley in 1997. Since then leaf rust has increased further with the detection of new pathotypes 5453P- in 2001 and derivative 5453P+ which is widespread in Western Australia (R. Park, pers. comm.) and occurs in epidemic proportions in some high rust risk barley production areas.

Ongoing research is required to identify, quantify, and where possible anticipate changes in pathogen populations across barley production regions in Australia. Early identification of these changes enables breeding programs to revise priorities in resistance breeding and associated research objectives.

Effective breeding strategies require understanding of pathogen variability/virulences

A major concern exists where changes in the virulence of the pathogen can overcome resistance present in the host. Over time, mutations and hybridization events can change the pathogen population structure and thus may defeat resistance genes present in recommended varieties. At present variability in barley leaf rust is identified through the Australian Cereal Rust Survey conducted by Plant Breeding Institute (PBI) Cobbitty (R. Park, University of Sydney). Similarly, scald is currently addressed in South Australia (H. Wallwork, South Australian Research and Development Institute (SARDI).

Considerable forethought and planning, increasingly at the national level, is required for managing changes in pathogen variability and virulence spectra with ongoing or periodic assessment for other diseases such as powdery mildew and net blotches to enable development of effective breeding strategies.

Understanding host resistance to enable development of breeding strategies

The *mlo* resistance to powdery mildew was identified in 1942 from a barley mutant (Jorgensen 1992). It provides durable levels of resistance. The different alleles of *mlo* are used in the development of barley material across Australia. A range of disease traits and catalogued matching disease resistance genes with their chromosomal map locations have been described (Cattivelli *et al*. 2002; Kleinhofs and Han, 2002; Williams, 2003). More recently, we have identified net type net blotch resistance genes on barley chromosomes 2H, 3H, 4H, 6H regions of the chromosomes under a national objective in Australian Winter Cereal Molecular Marker Program (AWCMMP). There is a high correlation of seedling expression with adult plant expression for major genes located on 4H and 6H and this provides excellent opportunities for their incorporation into adapted breeding material. Similarly, resistance genes for scald have been found on 3H, 4H and 6H from barley germplasm and advanced lines in Western and South barley breeding nodes.

A major gene for spot type net blotch resistance *Rpt4* on 7H was found in Galleon, CIho 9214, Keel, Tilga and VB9104 in the South Australian program, whereas 6H was found to be associated with resistance to this disease from Canadian barleys in Western Australia. The effectiveness of these genes was found to be partial at the adult plant stage and thus provides limited protection. This work identified aspects related to breeding strategies for incorporation of resistances and selection methods ensuring their relevance to commercial field growing environments.

Research at the University of Sydney Plant Breeding Institute in collaboration with Western Australia and Queensland programs is presently investigating seedling and adult plant resistances to leaf rust. Studies are underway to understand control and expression of resistance in a range of barley lines to devise effective strategies for combining genes utilized in breeding programs.

Some resistance genes have partial to complete protection against virulent pathotypes of the pathogen whereas others provide low levels of protection (e.g. spot type net blotch resistance). By understanding how major and minor genes function, when challenged by a pathogen of known virulence, more effective or durable host resistance can be developed. In addition, knowledge of the pathogen population can lead to

the utilisation of resistance genes under regional and national deployment strategies by breeding programs.

Current resistance targets have been identified under the National Plan of Barley Breeding Australia, but regional variations occur for some diseases. In this sense, resistance objectives for durable and broadly effective resistance to multiple leaf diseases such as leaf rust, net blotches, powdery mildew and scald may result in common objectives among the participating breeding nodes**.** Materials and information are shared nationally through enhanced communication activities of Barley Breeding Australia (BBA), AWCMMP and Australian Cereal Rust Control Program (ACRCP).

Uptake of resistance in breeding programs

Disease susceptibility in released varieties is a result of an imperative approach to breeding for yield and quality with less emphasis on desirable but not essential traits of disease resistances. Pragmatic breeding strategies dictate setting relevant priorities in order to manage the large array of breeding targets. Given the practical limitations of population sizes in segregating breeding material, resistance breeding has resulted in incremental improvements to specifically targeted diseases in progressive steps towards multiple disease resistance. Breeding material with improvement for multiple diseases like rust, scald and net blotches can provide improved grain quality and a competitive edge in export markets.

A range of research directed breeding strategies such as marker-assisted selection coupled with male sterile facilitated recurrent selection are in use for scald and spot type net blotch resistance breeding in the Western Australian program. Populations developed for research into net type net blotch research have provided information not only on gene identification and location, but also helped to identify double haploid lines with superior quality attributes (near infra-red parameters) and desirable resistance gene combinations (4H and 6H QTLs) to be used as parental lines.

Molecular markers in marker assisted selection

Molecular markers for genes under selection have been identified during the last decade after characterization of resistance genes and their linkages. Most of this work has been conducted under AWCMMP. In many instances, a suite of markers for resistance loci are available and are implemented in breeding programs around Australia (Table 3).

It is worth mentioning in particular the use of loose smut resistance gene *Run8* where it is impractical to screen in the field on a large scale. Validation of published marker information by targeted field screening has enabled its incorporation as a breeding target where this was previously not feasible in Western Australia.

Marker assisted selection for resistance has mainly focussed on single major genes with major effects. One area that has not been addressed is the implementation of molecular markers for minor genes which may assist in resistance durability. This is mainly because, to identify useful minor genes for different diseases and, secondly, their introgression into breeding material requires tightly linked molecular markers, thus, pyramiding resistance genes of interest to obtain adequate levels of protection against the pathogen. This is a challenge for all of us and requires further research including effective collaborations with overseas scientists working in this area.

Table 3: Disease resistant loci used in the marker assisted selection in Australian breeding programs

Disease trait	Disease resistance loci implemented in breeding		
	West	**South**	**North**
Powdery mildew	1H (*Mla*), 4H (*mlo9*, *mlo11*)	-	-
Net type net blotch	4H, 6H (*Rpt5*)	-	4H, 6H (*Rpt5*)
Spot type net blotch	6H, 7H (*Rpt4*)	7H (*Rpt4*)	7H (*Rpt4*)
Leaf rust	3H (*Rph7*), 5H, 7H (*Rph3*)	5H, 7H (*Rph3*)	2H (*Rph18*), 3H(*Rph7*), 5H, 7H (*Rph3*)
Scald	4H, 6H	3H	-
Barley yellow dwarf virus	3H (*Yd2*)	-	-
Cereal cyst nematode	2H (*Ha2*)	2H (*Ha2*), 5H (*Ha4*)	-
Loose smut	1H (*Run8*)	-	-
Spot blotch	-	-	7H(*Rcs5*)
Stem rust	-	-	7H (*Rpg1*)

Risk management and screening strategy

Various screening strategies can be followed to screen breeding material in early and late generation. Currently, individual nodes of BBA have disease screening strategies in place. Associated specialist screening for some diseases may be applied to material identified at the national level as a priority. Examples of specialist expertise are net blotches in Western Australia and Queensland, scald and CCN in South Australia and leaf rust in PBI, Cobbitty. To determine how well targeted resistances are being developed by regional nodes, a national program should undertake evaluation of advanced lines. This is currently accomplished through the co-operation of existing programs for elite barley germplasm (Elite Barley Disease Screening Nursery) with potential to integrate with the National Variety Trial program.

Field screening activities are often the most cost effective, but can be subject to uncertain outcomes due to seasonal climatic conditions being unfavourable for disease development. Thus the genetic gain for disease resistance is reduced. Risk management strategies through careful selection of reliable sites or, where warranted, use of multiple screening locations in conjunction with glasshouse/greenhouse work are ways to reduce the risks associated with field disease nurseries. Site diversification has been used in Western Australia for scald, spot-type net blotch and leaf rust with desired results. Glasshouse screening has been used for the net type net blotch where there is high correlation between seedling and adult plant resistances. Similarly, other material in different selection stages should be screened in more than one disease nursery wherever possible.

Another aspect of multiple environment disease testing is the screening of the material against different pathotypes of the pathogen which give different disease responses in other regions. This is presently addressed under the national program by conducting field trials for scald in New South Wales, leaf rust in PBI Cobbitty, Barley Yellow Dwarf Virus in Tasmania and net blotches in Victoria. The impact of screening of breeding material at the national level remains to be seen as this strategy is evaluated over future years.

Exotic threats

National strategies are required for managing exotic threats such as barley stripe rust, Russian wheat aphid and Ramularia leaf spot. Barley stripe rust is a significant exotic threat to the barley industry. Screening in

Mexico at CIMMYT is co-ordinated through PBI Cobbitty and provides excellent feedback on the status of advance breeding material. While this activity should remain coordinated through PBI Cobbitty, debate exists as to whether this level of testing provides an adequate strategy for protection of the Australian barley industry. In general, further consideration of exotic threats should be developed and implemented at a national level.

Resources for basic research

This paper highlights various aspects of barley pathology addressing issues of disease resistance that require a range of areas of basic research needed for better understanding for resistance breeding. These are outlined below.

- tools for characterizing pathogen populations including near-isogenic lines.
- basic fungal biology research including sexual stages / alternate hosts of the pathogen / epidemiology.
- IPM strategies for protecting crops, combining resistance, fungicide sprays and crop rotation
- understanding the elements of partial resistance.
- investigation of pathotypes in the pathogen populations to determine virulence/avirulence factors and identify genes for avirulence.

While pathology support components in the national barley breeding programs are focussed on screening of breeding material, a national approach to barley breeding through BBA and pre-breeding through co-ordinated funding agencies provide an opportunity to prioritise strategically important research areas so that limited pre-breeding resources can be best deployed through effective collaboration, to support resistance breeding objectives focused efficient production of high quality barley suitable for our current and future markets.

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