The 2000 Farrer Memorial Oration

Combating the Enemy

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Cereal growers and plant researchers are engaged in a constant battle with disease organisms - fungi, viruses and bacteria. Symptoms may occur on above-ground parts of the plant or on the roots. For wheat, barley and oats, fungal diseases are the most obvious and generally inflict the most damage. Chemical control of these fungi is a routine practice in some European countries, but is not so common in Australia, where the economics of fungicide application are not as favourable. Growing disease-resistant varieties is the ideal solution to the problem in any country. However, developing types that are resistant to all the main diseases of a particular area is a very difficult job.

Since the time that William Farrer started his wheat breeding program in New South Wales in 1889, Australian cereal breeders have endeavoured to improve disease resistance in order to prevent serious losses in farmers' crops. During Farrer's attempts to breed for resistance to rust diseases, he struck two difficulties. He didn't have available parent varieties that possessed genes determining a high level of resistance. He also experienced a succession of dry seasons when rust development was insufficient to allow effective selection of the more resistant (or less susceptible) breeding lines.

However, Farrer's new varieties had better rust resistance than the English varieties originally grown in Australia. His selection for earlier maturity also proved to be an advantage to Australian farmers because earlier crops avoided the most severe effects of rust and allowed wheat-growing to succeed in the drier areas of Australia. Of course Farrer was very successful in achieving improvements in yield, baking quality and adaptation to Australian growing conditions.

The relative importance of a particular disease varies between countries, and between different areas of each country. Severity of damage varies greatly between seasons - a disease may be virtually unseen for a number of years before favourable environmental conditions allow an epidemic to develop. Another reason for a sudden disease outbreak is the emergence of a new race (or strain) that possesses a virulence gene capable of overcoming the resistance gene of a major cereal variety. This latter scenario has been repeated many times in many countries, and each time it necessitates a renewed or re-directed effort by the breeders. It is particularly relevant to those fungal diseases that readily spread by wind-borne spores, such as rusts and mildews.

In Australia, the main effort in cereal breeding for disease resistance during the 20th century has been directed at wheat, with the emphasis on rust diseases. The work conducted on wheat rusts at the University of Sydney is an outstanding example of successful resistance breeding. Their main effort was directed at combating stem rust (Puccinia graminis), with later inclusion of leaf rust (Puccinia recondita) and stripe rust (Puccinia striiformis), the latter disease not being detected in Australia until 1979.

In the first half of the 20th century, single genes conferring resistance to stem rust were incorporated into new wheat varieties. However, the main problem with breeding for rust resistance is the variability of the fungus, and sometime later a new mutant strain would appear that could overcome the resistance gene, so it was 'back to the drawing board'. After these early disappointments of short-lived resistance, the Sydney University researchers set about developing wheats with combinations of resistance genes. They have continued along this path in co-operation with Australian wheat breeders. They also aim to keep a step ahead of the enemy, by predicting the virulence gene combinations of the next mutant rust strains, so that breeders have information about appropriate parent varieties.

Their approach to the problem has been rewarding. The wheat-growing areas of Queensland and northern New South Wales used to be the areas most vulnerable to stem rust epidemics. However, the use of resistant wheat varieties in these regions has resulted in little stem rust damage in the past 50 years. In contrast, areas of Australia that grew rust-susceptible wheats were occasionally subjected to disease epidemics, notably one in 1973, when it was estimated that losses to rust in south-eastern Australia totalled between $200 million and $300 million.

The 1973 experience led to the 'Australian Rust in Wheat Conference' and subsequent initiation of the 'National Rust Control Program' headed by the University of Sydney and involving wheat breeders and pathologists from around the country. This program was later expanded to include rust diseases of barley and oats. There has been a huge amount of thought, debate, and scientific research and development in order to protect Australian wheat growers from the ravages of rust diseases.

Cereal breeding programs in Tasmania have had disease resistance as a major objective. When I started work in the (then) Department of Agriculture in 1963, the main disease in Tasmanian cereal crops was caused by a virus known as Barley Yellow Dwarf Virus (BYDV). This is now recognised as the most widespread and damaging virus disease of cereals on a worldwide basis. It has a wide host range, including wheat, barley, oats, triticale, rye, corn and many other species in the grass family.

BYDV is transmitted by several species of aphid and can only survive on living plants. It was originally thought to be a single virus, but was later separated into several different serotypes. Symptoms vary according to the crop, variety, virus type, age of plant at time of infection and environmental conditions. Typical symptoms of early infection are leaf discolouration followed by dwarfing of the plant. The main internal symptom is necrosis of the phloem, leading to "starvation" of the plant and resulting in reduced growth above and below ground.

Agronomists, pathologists, entomologists and breeders have considered various options for combating this particular enemy, all of which present problems:

• Avoid early infection by sowing crops at a time when aphid flights are at a low point.

• Try to control the aphids by use of insecticides.

• Use management practices of stubble retention and direct drilling, which have been shown to affect aphid migration into a crop.

• Breed varieties resistant to the aphids.

• Breed varieties that are resistant or tolerant to the virus.

The word 'resistant' in this case signifies a reduction in speed of viral replication, while 'tolerant' means the plant can yield reasonably well despite a 'normal' level of viral replication.

BYDV was first recognised as a virus disease in the USA in 1951. American researchers tested many varieties and introduced lines to determine their reaction to BYDV infection. Certain Ethiopian barleys showed a high level of resistance or tolerance to BYDV due to a gene called 'Yd2'. Wheat and oat varieties also varied in their reactions, but none possessed a major gene with the effectiveness of Yd2.

I obtained seed of the more promising Ethiopian barley lines from the USA, and these were also resistant in Tasmania under severe infection pressure, while our standard malting variety Proctor (bred in UK) exhibited the classical symptoms of a susceptible variety. However, the Ethiopian barleys were not suitable for commercial production due to agronomic and quality deficiencies - this is usually the case when finding a desirable resistance gene in exotic material. At that time it didn't appear that any

BYDV-resistant malting barley would be released elsewhere in the near future, so we concluded that the only way to overcome the problem would be to start a breeding program in Tasmania with the initial aim of transferring the Yd2 gene into a Proctor genetic background.

It took three backcrosses of Proctor to an Ethiopian line before the desired agronomic and quality type was produced. Following intensive selection and field testing, the new variety 'Shannon' was released. Shannon was similar to Proctor in most respects, but produced much higher yields than Proctor when BYDV infection was severe.

Having the YD2 gene in a more desirable (European-type) genetic background made subsequent breeding more straightforward, because further backcrossing was not necessary. The BYDV-resistance of Shannon was later combined with resistance to certain fungal diseases in the variety 'Franklin'.

I have noticed that BYDV infections of Tasmanian cereal crops have not been as severe in the past 20 years compared with the epidemics of the 1960's and 1970's, even when seasonal conditions appear to suit the breeding and survival of aphids. Apart from the improved resistance of current varieties, there may be another factor influencing the observation. Resistant varieties that reduce virus multiplication will help restrict the number of virus particles transmitted to another crop or to the main alternative host, perennial ryegrass. This will have a compounding effect over time. So it appears that development of BYDV-resistant varieties has been beneficial in both reducing the vulnerability of crops and the amount of virus available for transmission by aphids.

During the early years of barley breeding, I thought that the Yd2 gene must be closely linked to a gene for resistance to the fungal disease leaf scald (Rhyncosporium secalis), as these two resistances were present in the Ethiopian parent, and were generally found together in the selected progeny, including Shannon. In recent years, a scald resistance gene has been mapped very close to Yd2. Unfortunately, this scald resistance was overcome in Tasmania by strains that are virulent on Franklin and which increased when Franklin became the dominant variety here.

The same type of event has recently occurred in relation to leaf rust (Puccinia hordei). When Franklin was released in 1989 it was resistant to strains of leaf rust prevalent in Tasmania, but two new virulent strains appeared in 1999, so Franklin is now classed as susceptible in this State.

This type of 'breakdown of resistance' experienced for fungal diseases has not occurred for the viral disease BYDV. The Yd2 gene has maintained its effectiveness over a long period. Although this gene is less effective in slowing virus multiplication for certain strains (isolates) of BYDV, these are not the common strains in Australia or in most other countries. Fortunately the type of 'boom-and-bust' cycle experienced with rust resistance breeding has not been a problem for our BYDV-resistance program. This virus has not shown the same capacity for mutation and spread of new strains as have fungal diseases of cereals.

The other main Tasmanian cereal breeding project has been conducted on oats. As for barley, a major objective was to improve resistance/tolerance to BYDV, and we have been successful in this pursuit with release of the varieties Esk, Nile, Bass and Targa for grazing and grain production. The Western Australian variety Avon was considered a particularly suitable parent for the crossing program in the 1960's, and although the genetic basis for its resistance was not known, we were able to select new varieties that inherited Avon's ability to withstand BYDV infection without significant yield loss. In later years we registered a Canadian line under the name of Quamby, and used it as an additional source of virus resistance.

I find it interesting to reflect on the 'snow-balling' effects that research or breeding at one location can have on subsequent disease resistance work. The identification of BYDV and search for resistant or tolerant varieties in the USA in the 1950s led to worldwide research on the disease and the realisation that BYDV was causing serious damage to cereal crops in many countries. Numerous scientific papers and information articles have been written in the past 40 years, and breeders around the world have endeavoured to improve the BYDV resistance of cereal varieties during that period.

Looking at the local scene, the barley breeding in Tasmania appears to have stimulated other Australian research on the disease, especially in relation to the Yd2 gene. The availability of Shannon, its (very similar) parent variety Proctor and its Ethiopian parent enabled investigations on the action and effectiveness of the Yd2 gene. Research by CSIRO showed how barley varieties possessing Yd2 varied in their reaction to BYDV, depending on their remaining genetic make-up. The reaction also depended on which serotype and which isolate (strain) of that serotype was infecting the plants.

Further work at CSIRO has led to new approaches toward developing BYDV-resistant varieties of barley and wheat - some would fall into the category of biotechnology or genetic engineering. In this project, various strategies using BYDV coat protein and polymerase genes and satellite RNA genes have been employed with the aim of developing an even higher level of resistance in barley than that offered by Yd2. With regard to wheat, the perennial grass species Thinopyrum (Agropyron) intermedium has been used as a source of resistance in developing translocation lines at CSIRO. This resistance appears the most promising for wheat breeders to date, proving effective against a range of serotypes and the majority of isolates in various countries.

In more traditional breeding, Franklin and other Tasmanian barley lines have been used as the source of BYDV resistance in Australian programs, as these were the most suitable parents containing the Yd2 gene.

It is hard enough for breeders to keep up with diseases presently in Australia, but consider diseases present in other countries that have not yet found their way to Australia, as well as different strains of current diseases. Spores of these could arrive at any time with overseas travellers. Can we afford to dilute our efforts by breeding for resistance to these potential problems? It depends on the serious nature of the disease. An example of this situation is work that has been started to improve the resistance of Australian barley varieties to barley stripe rust, which could be devastating if strains from the Americas arrive here.

How will breeders conduct the future battle against the whole range of diseases that can damage Australian cereal crops? Traditional (standard) plant breeding will be around for a long time yet, and will increasingly be aided by breakthroughs in biotechnology. These new techniques have the potential to improve the disease screening of breeders' lines, speed up production of new varieties and overcome some of the disease problems that have so far proved too difficult to combat by standard breeding methods. All things considered, there appears to be much work ahead for agricultural scientists in trying to 'Combat the Enemy'.

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