1-1-1987

Increasing protein content of wheat by breeding

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Increasing protein content

By Bryan Whan1 and Graham Crosbie2

The most efficient means of increasing protein content of Western Australian wheat is by breeding new varieties with higher inherent protein in their grain. But is this possible without sacrificing yield or other desirable characteristics?

Potential for improvement of protein

A survey of more than 12,500 wheats from the United States Department of Agriculture wheat collection by Johnson and colleagues at Nebraska indicated that, while the average protein content of the wheats surveyed was 13 per cent, the protein content of different wheats varied from 6 to 22 per cent. About one third of this variation was genetic and could be used in breeding; the rest was due to environmental difference.

Breeding for increased protein is complicated by two important issues. Depending on growing conditions, high yielding varieties are not always high yielding, and, in the same way, high protein varieties may not always produce grain with high protein content. Environment exerts a strong influence on protein content in the same way that it influences yield. In addition, increased grain protein is often associated with reduced grain yield. The important consideration is whether we can develop varieties with higher protein content than other varieties of the same yield, grown in the same environment. Overseas experience indicates this should be possible.

Overseas experience

Atlas 50 and Atlas 66, bred by Middleton and colleagues in North Carolina, U.S.A., were the first wheat varieties developed that gave significant improvements in grain protein through breeding. They were comparable in yield with commercially grown U.S. soft winter wheats and produced grain with significantly higher protein content. The increased protein of these varieties came from a Brazilian parent Frondoso, which was actually used for leaf rust resistance. The increased protein content was fortuitous.

Nap Hal, an old soft red spring Indian variety, was identified as a high protein and a high lysine wheat from surveys of wheat collections. Genetic studies showed that Nap Hal and Atlas 66 contained different major genes for protein content, suggesting that these sources could be combined to achieve further increases in protein content. A Korean variety, Jang Kwang, also has been used as a source of high protein.

In addition to the major genes that occur in varieties such as Atlas 66 and Nap Hal, minor genes probably exist in other wheats. Lines with increased protein have been selected by Klepper from spring wheat populations developed by the International Maize and Wheat Improvement Centre (CIMMYT), even though the parents were not known to have high protein.

Several varieties have been developed in Nebraska and Kansas using these and other high protein parents. It is claimed that these varieties, such as Lancota, Parker 76, Dual V, and Plainsman V, contain as much as two per cent more protein and yet yield as well as the older varieties.

Wheat-related species as sources of high protein

Wheat-related wild species, including Agropyron elongatum (tall wheat grass), Aegilops squarrosa (goat grass), Triticum timopheevii and Triticum turgidum dicoccoides (wild emmer), may be useful as sources of genes for high protein. However, novel approaches to breeding must often be adopted to transfer genes from wild species to the common bread wheats, making the exploitation of this germ plasm a difficult task.

Kushmir and Halloran have recently transferred high protein genes from wild emmer (T. turgidum dicoccoides) into some Australian varieties, providing useful material for Australian wheat breeders.

Protein accumulation in the grain

Research at Nebraska showed that the high protein genes from Atlas 66 increase both the uptake and translocation of nitrogen in the plant. A greater amount of soil nitrogen is absorbed and a higher proportion is translocated to the grain. The level of the enzyme, nitrate reductase, in the foliage of high protein varieties Atlas 66, Nap Hal, and their derivatives is higher than in other varieties. This enzyme is important in the production of protein and it may be a limiting factor. It has been suggested that increasing the production of nitrate reductase may increase grain protein content.

In Atlas 66 the additional protein occurs in the flour, whereas in Nap Hal it occurs in both the flour and bran. All the high protein effect of Atlas 66 derivatives and much of that of Nap Hal derivatives could therefore be expected to be beneficial in flour products.

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Breeding for increased protein content in Western Australia

The Department of Agriculture started a small project in 1983 to develop varieties for Western Australia with increased protein content. Many high protein breeding lines incorporating the parents previously described were assessed for their suitability for crossing with our wheats. Unfortunately, many were unsuitable, as they were winter types with red grain. This makes the task of producing white grained, spring types difficult. The following four parents were chosen from the CIMMYT, Nebraska, and University of Melbourne breeding lines, and crossed with appropriate Western Australian wheats:

- HIP-SP7: A white grained selection by Klepper from CIMMYT material
- HIP-SP11: A red grained line from Nebraska (NAP HAL/ATLAS 66//LIKAFEN/ATLAS 66/COMANCHE/HUME)
- HIP-DIC2 and HIP-DIC3: Red grained wheats derived from crosses made by Kushnir at the University of Melbourne between Triticum turgidum dicoccoides and the Australian cultivar Warimba.

After preliminary assessments in 1985, selections from these crosses were assessed in detail for grain yield and protein content at Wongan Hills Research Station in 1986. Nearly 200 selections were tested, but data for the 15 most promising lines only are discussed here. Some of the crossbreds gave satisfactory yields; crossbreds 2 and 3 yielded as well as their Gutha parent (Table 1). A number of others were low yielding, but this is not surprising from a single cross with these high protein parents that are not well adapted to Western Australian conditions.

Table 1. Grain yield, protein content, protein yield and grain hardness of some crossbreds from high protein parents, Wongan Hills, 1986

<table>
<thead>
<tr>
<th>Variety/crossbred</th>
<th>Control varieties</th>
<th>Crossbreds with relatively high protein yield</th>
<th>Crossbreds with relatively high protein percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain yield (t/ha)</td>
<td>Protein content (%)</td>
<td>Protein yield (kg/ha)</td>
</tr>
<tr>
<td>Bodallin</td>
<td>2.32</td>
<td>8.4</td>
<td>194</td>
</tr>
<tr>
<td>Gutha</td>
<td>2.31</td>
<td>8.1</td>
<td>187</td>
</tr>
<tr>
<td>Eradu</td>
<td>2.18</td>
<td>8.5</td>
<td>185</td>
</tr>
<tr>
<td>Kulin</td>
<td>2.52</td>
<td>8.3</td>
<td>209</td>
</tr>
<tr>
<td>Gutha/HIP-SP 7</td>
<td>2.18</td>
<td>8.8</td>
<td>192</td>
</tr>
<tr>
<td>Gutha/HIP-SP 7</td>
<td>2.41</td>
<td>9.0</td>
<td>217</td>
</tr>
<tr>
<td>Gutha/HIP-SP 7</td>
<td>2.31</td>
<td>9.0</td>
<td>208</td>
</tr>
<tr>
<td>Cranbrook/HIP-SP 7</td>
<td>2.13</td>
<td>9.7</td>
<td>207</td>
</tr>
<tr>
<td>Millewa cross/HIP-DIC 2</td>
<td>2.26</td>
<td>8.8</td>
<td>198</td>
</tr>
<tr>
<td>Bobwhite/HIP-SP 7</td>
<td>2.18</td>
<td>8.9</td>
<td>207</td>
</tr>
<tr>
<td>Millewa/HIP-SP 7</td>
<td>2.25</td>
<td>8.9</td>
<td>207</td>
</tr>
<tr>
<td>Condor/HIP-SP 11</td>
<td>1.98</td>
<td>10.4</td>
<td>206</td>
</tr>
</tbody>
</table>

• Below: The high protein crossbreds developed locally are crossed again to further increase their yield and protein content. Crosses, made by hand pollination in the glasshouse, are tedious and labour intensive and the grain obtained is valuable. These grains represent the start of 10 years breeding work that may produce a new variety.

Right: Some of the best sources of high protein are winter wheats such as the lines from Kansas and Nebraska, U.S.A. in the foreground of this photograph. These wheats will not come into head in usual Western Australian environments so crossing these parents with appropriate local wheats, and evaluating their progeny, is difficult.
Figure 1. Grain yield and protein content of some crossbreds from high protein parents compared with that of control varieties. (See Table 1 for the keys to crossbreds 1 to 15). All crossbreds have higher protein contents than the controls, but some have lower yields. Crossbreds 2 and 3 are the most promising as they have higher protein content than the controls at the same yield level.

Further reading

Acknowledgements
This project was supported by the Wheat Research Committee of Western Australia. The technical assistance of S. Brown, K. Jose, A. Kuss, B. Rees, D. Sutherland and M. Walsh is gratefully acknowledged.

Harvesting trial plots of wheat at Wongan Hills Research Station. Nearly 200 selections of crosses of high protein wheat lines were planted in 1986.

All the crossbreds had higher protein contents than the control varieties, some as much as two per cent higher. However, this can be misleading as there is a negative relationship between grain yield and protein content (Figure 1). Protein yield, the product of grain yield and protein content, is therefore a better comparison.

Kulin, the most recently released Western Australian variety, gave higher yields than the other control varieties and yet maintained its protein content. The yields of the crossbreds 1 to 8 were similar to the controls but their protein contents were markedly higher. Furthermore, their protein yields were higher than those of Bodallin, Gutha and Eradu. The crucial question is whether improvements in protein content can be achieved with crossbreds at the same yield level as the comparable control variety. Crossbreds 2 and 3 have achieved this as they had comparable yields to their Gutha parent but with an increased protein content of 0.9 per cent.

Crossbreds 9 to 15 had high protein contents but low yields. They also had high protein contents in the preliminary assessments in 1985, so they are consistent in this character. Part of the increased protein contents of crossbreds 9 to 15 was probably a direct result of their low yield, but how much is not known. Could the high protein contents be maintained, or partly maintained, if the yields of these crossbreds are increased through further breeding?

Increased yields have been achieved with varieties such as Kulin, without reductions in protein content and this suggests that it may be possible to increase protein content, to some extent at least.

Conclusion
Breeding for increased protein content of wheat is complex. Most high protein parents are ill-adapted to Western Australian conditions, and it is often difficult to demonstrate real progress in protein content, independent of yield. We may have achieved some progress with this breeding material in developing crossbreds with increased protein content at similar yields to an appropriate control variety, but further work is required to confirm this. Some of the crossbreds with high protein contents may prove useful as parents for further crossing.

The full set of crossbreds was reassessed in 1987. Crossing is being carried out to further increase the yields and protein contents of this material.