WHEAT BREEDERS MAKE IT HAPPEN. Dr. Lindsay O'Brien.

To demonstrate that wheat breeders make it happen some examples will be described. The first two are well known and documented. The main example, however, forms the basis for trading grain internationally so may not be obvious. The data that will be presented and a knowledge of the way the grain market operates will advance the case that the trading of milling grades of wheat is dependent on the focus on selecting for quality by wheat breeders.

William James Farrer, pioneering wheat breeder.

William Farrer laid the foundations for the growth of the wheat industry in Australia in the 20th century with the release of Federation. Prior to its release the wheats being grown were either direct introductions or farmer selections from introductions and they flowered and matured too late for Australian conditions. The release of Federation in 1901 set the developmental pattern of what was needed in a variety adapted to Australian conditions. Federation dominated the national wheat area for nearly twenty-five years. William Farrer made it happen.

Farrer was in regular contact with breeders around the world including Blount in the USA and Vilmorin in France. A germplasm exchange with Blount resulted in Federation being grown in the Pacific North West region of the United States. This unintentionally donated to the region the change in wheat starch composition that research some 70 years later would identify as being the result of a deletion in the gene sequence that altered the ratio of the two starch polymers, amylopectin and amylose. This change is responsible for giving the desired mouth feel of premium quality white salted noodles consumed in Japan (Udon) and Korea. Today, the two major markets that supply wheat for this product are Western Australia and the Pacific North West of the United States.

The wheat rusts and development of the industry.

The expansion of wheat production in Australia was being limited by the poor adaptation of the introduced varieties or the selections from them and their susceptibility to the wheat rusts, mainly stem rust. In the years when rust was prevalent, severe losses of production occurred resulting in the convening of a series of Intercolonial Rust in Wheat Conferences in the 1890's. Farrer made a written submission to the first and attended the second where those present, representing their respective colonies, committed to the breeding of rust resistant varieties.

Farrer was committed to this goal and the crosses he was making at his property Lambrigg, near Canberra were directed at that end, but a thorough knowledge of the pathology of the wheat rusts and the genetics of host plant resistance were yet to develop.

Cereal rust investigations were commenced at the University of Sydney about 1920 by W. L. Waterhouse (Watson, 1985). Germplasm obtained from McFadden in the United States included the varieties Webster and Hope. The resistance in both these varieties was backcrossed into Federation, resulting in the naming in 1937 of Fedweb (Federation/Webster) and Hofed (Hope/Federation) as the first rust resistant varieties (Macindoe and Walkden Brown, 1968). The resistance genes in the donor varieties were later catalogued (McIntosh, Wellings and Park, 1995) as Sr30 (Webster), and Sr2 (Hope) and are still being used by breeders today. Sr2 is a gene that gives an adult plant slow rusting reaction to stem rust and in combination with other genes forms effective resistance to the rust race complex Ug99 which poses a threat to global wheat production. Waterhouse the wheat breeder, made it happen.

The University has maintained its commitment to rust research and the development of resistant varieties since the Waterhouse era. However, it was the vision of regional growers to establish a research centre on the rich black soil plains of the north west of NSW where the major impact would be delivered. Once at the mercy of the ravages of rust, losses as high as 51% in 1947-48 were experienced (Table 1). The industry suffered badly, not only through the loss of production, but the rust damaged grain was useless for milling or livestock feed (Figure 1).

Year	% loss of production
1930-31	26
1934-35	46
1936-37	3.0
1939-40	25
1947-48	51
1948-64	None recorded
1964-65	0.5
1965-74	None recorded
1975-present	None recorded

Left: Figure 1. The impact of stem rust infection on wheat grains. Grain from healthy plants (top) and severely rusted plants (bottom).

Right: Table 1. Estimates of losses of production from stem rust in the north west of NSW up to 1974 (Derera, 1977) and since 1975 to the present day.

No losses have been sustained in northern NSW and Queensland since 1965. Even in the disastrous stem rust epidemic that caused losses of production estimated at $100 million in southern Australia in 1973 no losses occurred because only resistant varieties are grown. Wheat breeders made it happen.

Australia a major wheat exporting country.

Australia is a top ten wheat producing and exporting nation. To maintain exports in an ever increasingly competitive world trading market, the wheat must meet the requirements of discriminating buyers.

Wheat is accumulated at receival points by grain trading companies into any one of a number of different grades based on growers declaring the name of the variety and grain quality measures, such as moisture and protein content, test weight, absence of foreign matter, low screenings (small and cracked grains) and freedom from weather damage (high Falling Number). This has resulted in Australian wheat having the reputation of being clean, dry and white.

Declaring the variety when grain is sold, provides the quality guarantee for the wheat in each grade. Each variety is a genetic package that can handle the wide range of environmental conditions of the

Australian wheat belt but still deliver the functional quality (the wide range of end products that can be made from wheat) to customers that buy the wheat. How do wheat breeders make that happen?

To be eligible for receival into a milling grade, every variety is assessed by an expert panel appointed by the independent company, Wheat Quality Australia (WQA). Breeders need to submit data on grain, flour and end-products such as breads and noodles produced using WQA approved methods. Data from six sets of samples from at least three seasons, with end-product data for two of those years is examined. Breeders also must be able to understand and interpret such data to make selection decisions and progress materials in their breeding programs towards becoming a variety.

Every variety that gets received into a milling grade is thus the result of selection by wheat breeders using data over generations, sites and years. Using variety and receival specifications for each grade enables the market to sell wheat based on the difference between grades which is mostly seasonally driven variation in protein content and the quality measures correlated with protein content. However, the process is not as simple as just selecting for protein content. Variation in "protein quality" must also be considered.

"Protein quality" can be seen in Figure 2 which reproduces the work of Finney and Barmore (1948).

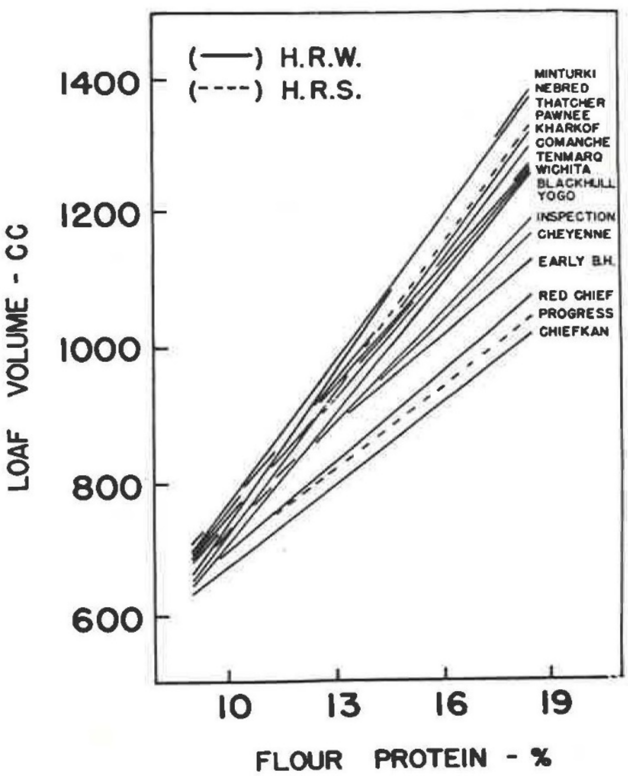


Figure 2. Demonstration of differences between wheat varieties from two classes of US wheat due to "protein quality" (Finney and Barmore, 1948). Reproduced, by permission, from Finney, K. F., and Barmore, M. A. 1948. Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25:291-312.

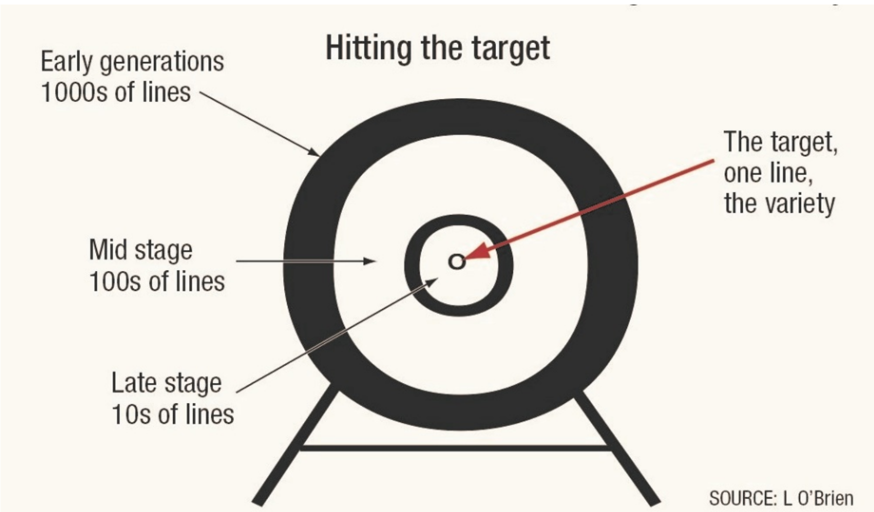
In the two classes of US wheat they demonstrated there was a wide range in bread loaf volume at the same protein content that was evident across a large spread in flour protein content. At 13% flour protein content, for example, loaf volume could vary by 25 %, a difference between the varieties in "protein quality". Breeders need to account for variation in protein quality by selecting for it on-route to developing every new variety.

Breeders need to actively select for protein quality because the relationships between protein content and dough properties and product quality like bread loaf volume, while strong in developed varieties, can be weak to non-existent in segregating early generation breeding populations. An example of the relationship between flour protein content and the dough properties Extensograph maximum resistance (r = 0.344) and extensibility (r = 0.266) in unselected F3 generation breeding lines had a wide range of values for protein content and each Extensograph measure.

Breeders need to work with these types of relationships in the thousands of early generation lines in their programs, with the limitations of having small amounts of seed (grams) for quality testing and for planting the next generation. This is achieved using high daily throughput tests, 50-100 tests per day. The development of Near Infrared Reflectance spectroscopy methodology resulted in breeders being able to predict grain hardness, protein content and potential protein quality from ground samples of as little as 10g of seed. Advances in spectroscopy to Near Infrared Transmission instrumentation permit non-destructive testing, meaning all seed is retained for planting. Advances in biotechnology in the last twenty years see breeders selecting at the gene level using molecular markers for key genes that determine differences in protein and starch composition. Molecular based approaches can be applied to select for the best gene combinations or to remove genes with adverse effects on quality and for selection at the whole genome level for quality in combination with superior agronomic traits and disease resistances.

Irrespective of which approach breeders chose, data is generated on protein content, grain hardness, potential milling yield, flour colour, and a prediction of each lines' potential dough and end-product properties. This strategy reduces the numbers of lines from thousands to hundreds which can then be assessed using larger scale tests and even bread baking and noodle assessments.

Application of these strategies is supported by many research studies, but two Australian based examples, Jardine Moss and Mullaly (1963) and Orth, O'Brien and Jardine (1976) demonstrated that as few as four or three key measures, respectively, could capture the essence of something as complex as wheat quality. Practical breeding experience validates the research findings.



Source: Understanding Australian Wheat Quality.

Figure 3. A graphical representation of how breeders work through the thousands of lines they handle using assessments of quality towards the eventual target of a new variety.

When numbers have been reduced to hundreds, extensive disease assessments and region wide yield testing further reduces numbers. Seed (kgs) is now available for detailed testing where daily throughput can be as low as 8-12 samples per day, involving milling, dough quality, baking and noodle quality. These tests produce data for the breeder to further select each breeding line towards the quality target while generating the data to get a receival classification.

Selection for quality takes place because wheat is a food grain, processed in various ways to make a wide range of nutritious and delicious products. If some of these products are arranged on a diagonal like in Figure 4, the optimum flour for each product increases in dough strength, combined with extensibility as we go up the diagonal from cakes to pan breads and pasta. The optimum flour can be further defined by differences in grain hardness in a vertical direction and protein content horizontally.

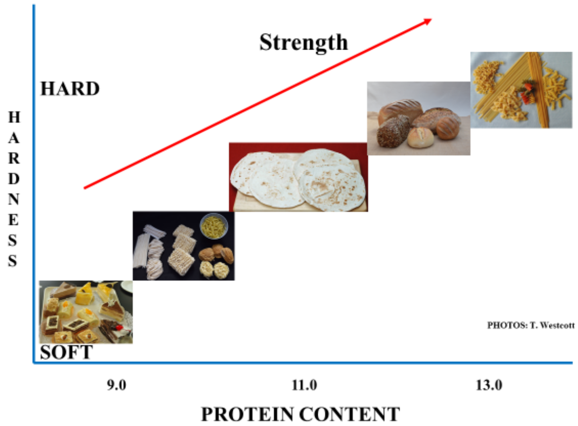


Figure 4. Some examples of wheat products arranged on a diagonal of increasing dough strength, with grain hardness vertically and protein content horizontally.

These relationships were first captured diagrammatically by Moss (1973). The boxes for each product category are important as they show that a range in protein and hardness values can be tolerated for each product grouping. The range allows for genetic variation between varieties and the effect of seasonal environment, a major determinant of final grain protein content.

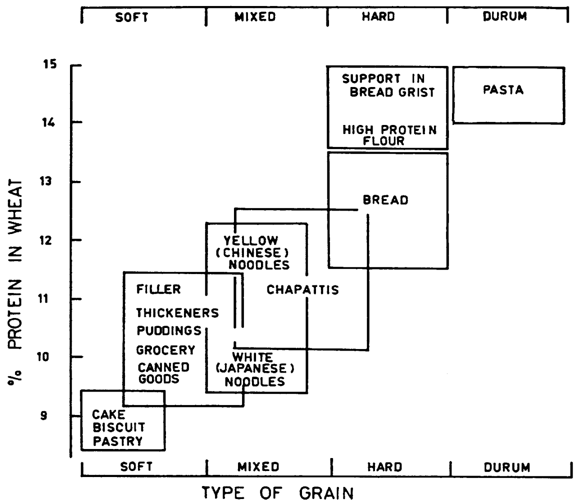


Figure 5. The relationship between grain hardness and protein content for products that can be made from Australian wheat. (Reproduced with permission of Ag Institute Australia).

What Moss first described in Figure 5, can be represented another way by replacing the boxes with end-products on the diagonal and Australian grades of wheat on the vertical axis (Figure 6) as was published in the NSW Department of Agriculture and Fisheries “Guide to Growing Better Wheat” (Anon, 1989).

Figure 6. The relationship between the wide range of end-products that can be made from Australian wheat, wheat protein content and the Australian wheat grades (Source: NSW Agriculture and Fisheries, 1989).

Conclusions.

The maximum receival classification of each variety is a major determinant in grower choice as its sets the maximum price that could be achieved should the wheat meet the receival standards for that grade.

Such an outcome is only possible because wheat breeders make it happen. Breeders produce the genetic package, the variety, that given the right seasonal conditions, will produce grain meeting the maximum grade for which it was classified and released.

Variety is the key within each grade. It is essentially a quality guarantee, made possible by wheat breeders selecting for quality which meet the standards set and assessed by an expert panel.

Grain is traded internationally using grain hardness as a major grade differentiator (Hard versus Soft) and variation in protein content between grades (Australian Prime Hard versus Australian Hard and Premium White). Variation within a grade is minimised via variety eligibility, thereby delivering to customers the functionality they need.

The market can operate using such quick, accurate and easy descriptors of quality because wheat breeders have selected in their breeding programs to make it happen.

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Sources.

Anon (1989). The Farmers Guide to Growing Better Wheat. “Operation Quality Wheat”. NSW Agriculture and Fisheries. Agricultural Research Centre, RMB 944, Tamworth, NSW, 2340.

A.B. Blakeney, R.L. Cracknell, G.B. Crosbie, S.P. Jefferies, D.M. Miskelly, L. O’Brien, J.F. Panozzo, D.A.I. Suter, V. Solah, T. Watts, T. Westcott, R.M. Williams (2009) Understanding Australian Wheat Quality. A Basic Introduction to Australian Wheat Quality. Copyright. Wheat Quality Objectives Group, Australia, 2009.

Archer Russell (1949). William James Farrer. A Biography. F.W. Cheshire, Melbourne and London.

N. F. Derera (1977). Million Dollar Men. The Wheat Researchers. North Western Courier, Narrabri, NSW, No. 90. November 29, 1977, pp 12-13.

K.F. Finney and M.A. Barmore (1948). Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25: 291-312.

R. Jardine, H.J. Moss and J.V. Mullaly (1963). Wheat quality: a factor analysis of some test data. Aust. J. Agric. Res. 14: 603-621.

S.L. Macindoe and C. Walkden Brown (1968). Wheat Breeding and Varieties in Australia. Third edition. Division of Plant Industry. Science Bulletin No. 76. New South Wales Department of Agriculture.

R.A. McIntosh, C.R. Wellings and R.F Park (1995). Wheat Rusts: An Atlas of Resistance Genes. Copyright. CSIRO, Australia, 1995.

H.J. Moss (1973). Quality standards for wheat varieties. J. Aust. Inst. A. Sci. 39: 109-115.

R.A. Orth, L. O’Brien and R. Jardine (1976). A factor analysis of bread wheat quality tests. Aust. J. Agric. Res. 27: 575-582.

I.A. Watson (1985). The Development of the Plant Breeding Institute. In: Annual Report 1985 of The University of Sydney, Faculty of Agriculture, Plant Breeding Institute. Department of Agricultural Genetics and Botany, pp 11-20.