The Farrer Memorial Oration 2015

Will current plant breeding for grain-quality traits be applicable in a changing environment?

Dr. Joe Panozzo

Department of Economic Development, Jobs, Transport, and Resources: Horsham, Victoria

19 August 2015

I am honoured to receive the William Farrer award and thank the Farrer Trustees and the NSW-Department of Primary Industries for this very prestigious award. This award represents a highlight in my career for which I am truly proud. In accepting this award, I acknowledge my fellow grains chemists and plant breeders with whom I've had the privilege of working during my career associated with crop improvement programs.

I would also like to thank the University of Sydney; Charles Perkins Centre, Marie Bashir Institute and the organisers of this symposium; "Resetting the Australian Table" for opportunity to present my oration today.

During my career as a grains research scientist, I have been fortunate to have worked on five major broad-acre crops: wheat, barley, canola, lentils and field peas. Each of these crops have a unique role in agriculture and play an important part in food manufacture and human nutrition.

In my oration, I will outline breeding objectives leading to improvements in grain quality and discuss the main industry drivers for each crop. I am mindful the audience at this symposium have an interest in food security and nutrition and so I will discuss where the current gaps in plant breeding are in relation to this field of science.

Historically, plant breeding in Australia was undertaken by state departments of agriculture, universities and CSIRO. The emphasis has been on developing varieties that are best for the Australian grains industry using the principles first used in Australia by William Farrer. In the past 10 years, state governments have withdrawn from directly breeding the major cereal and oilseed crops, as this role has been taken over by the private sector. As a result the emphasis is now to develop more widely adapted crops with broader end-use quality characteristics.

Nonetheless, the aims remain the same, to develop new varieties which are adapted to a specific growing region, soil-type and set of environmental conditions. Each new variety is, in theory, better than the previous variety as plant breeders introduced new germplasm with a combination of genes for improved resistance or tolerance to plant diseases contributing to increased grain yields. Similarly, the grain-quality chemist has identified through extensive germplasm screening, a new line with improved quality traits. This team consisting of breeder, chemist and pathologist has proven to be very effective in Australian wheat improvement programs.

The development of a new variety is the culmination of between eight and 12 years of extensive testing, and during the course of testing, thousands of germplasm lines are discarded because they fail a particular test. What may not be apparent to those not directly associated with plant improvement is that there is a need to look into the future to foresee issues which may arise in 10 years' time. These issues may be related to the emergence of a new plant disease, issues related to climate, specific requirements of new markets or a change in food trends.

The development of successful varieties is becoming increasingly more difficult. Scientists try to combine genes which confer increased grain yields, improved agronomic traits for adaptability in a changing environment and resistance to pests and diseases as well as ensuring the grain meets market specifications. I will now outline the major quality traits in broad terms for these five crops, identify which industry sectors are the drivers for improving grain quality and identify possible gaps in the market which receive less attention.

Wheat

Wheat is the major broad-acre crop grown in Australia. Approximately 23 million tonnes are produced annually. The majority of the wheat is exported to South-East Asia, Japan, South Korea and the Middle-East. Domestically, wheat is milled into flour and used predominantly by the baking industry. The primary quality targets are; large grain size, protein percentage between 10 and 14% to align with a particular market class, improved flour yield and white flour colour and dough rheology which optimises bread quality and processing characteristics within the bakery.

Table 1: Wheat

Product	**Macro quality traits**	**Drivers**	**Resources allocated for improving quality traits**
Grain	Grain size	Industry	Large
Flour	Milling yield, colour	Flour mills	
End-products: *Breads, Pasta Biscuits….*	Dough mixing properties Bread quality	Automated bakeries Supermarkets	
Niche market health products	Increased wellbeing • Reduced allergy to gluten • Increased resistant starch*	Consumers	Small

*Commercial bread available with high RS

Underlying these broad traits are the contributions of proteins and carbohydrates; their composition controlled by multiple genes located on different chromosomes; and their expression altered by the effects of environmental conditions during grain development. This may appear to be relatively easy task to simultaneously improve grain yields and disease resistance and quality traits. However pleiotropic effects can often alter the desired outcome and hence the need for extensive multi-site and multi-year testing.

In a highly competitive commercial environment, gaining or maintaining market share is important for profitability and therefore breeding programs target, quality traits to align with the largest markets and therefore quality traits for smaller niche markets are often not addressed.

Wheat is also the grain which receives the greatest public scrutiny in terms of allergies and intolerances and whilst there have been attempts to address these issues, the task has proven to be complex without compromising mainstream quality targets. A case in point is to develop wheat suitable for coeliac patients. To address this issue would require down-regulating coeliac-toxic proteins such as gliadins without compromising the gluten structure and baking quality.

Similarly, the development of a wheat variety with increased resistant starch is generally not compatible for grain yield and grain size with most commercial cultivars as increasing the resistant starch, involves a shift in the starch biosynthesis pathways altering the relative synthesis of amylose and amylopectin. The result is often smaller or partially-filled grains contributing to reduced grain yields.

Barley

Barley is a high value grain, particularly if the variety meets the industry specification for malting grade barley. These variety-specific parameters are defined by large grain size, a specific protein percentage window and optimal levels of protein- and starch degrading enzymes which are synthesised during the germination or malting process and resulting in maximum conversion of protein and starch for optimal beer production and quality. For malting barley, the β-glucan levels which are components of cell walls must be very low as their presence creates filtration problems during the production of beer. However, from a human wellbeing perspective, we know that β-glucans have an important role in preventing the absorption of cholesterol, and so there is a conflicting issue of what the industry requires to produce a high-quality beer and what the consumer requires to reduce LDL cholesterol. It is therefore apparent that one type of barley is not suitable for both markets. To this end, the CSIRO developed BARLEYmax which is higher in dietary fibre and resistant starch than commercial malting barley varieties.

Table 2: Barley

Product	**Macro quality traits**	**Drivers**	**Resources allocated for improving quality traits**
Malt	Optimum development of carbohydrate and protein degrading enzymes	Malting industry	Large
Beer production	Optimal alcohol yield Low β-glucan Low beer-haze proteins	Brewing companies	
Feed barley	Grain size Protein percentage Metabolisable energy	Stockfeed Industry	
Niche market health products *For example,* (BARLEYmax*)	High β-glucan High resistant starch	Health-conscious consumers	Small

*Developed by CSIRO and partners

Canola

Oilseed crops such as canola are either exported or processed within Australia into a range of oil products. Of all broad-acre crops, canola breeders have been able to target a range of industry sectors to produce oil for diverse end-uses and also for human health. This wasn't always the case as the predecessor to canola in the 1960s was rapeseed. The oil from rapeseed contained high levels of the erucic acid and the seed meal was high in glucosinolates. It was found that erucic acid was deleterious to human health and glucosinolates were unpalatable for live-stock. With the introduction of canola, an acronym for Canadian Oil Low Acid, the presence of these compounds was reduced to very low concentrations. The emphasis of the canola industry was to improve the quality by selecting fatty acids with enhanced or decreased fatty acid concentrations for use as an edible oil for cooking. The aim was to make the oil more healthy by increasing the oleic acid levels or to improve the frying stability by decreasing linolenic acid levels.

Table 3: Canola

Product	Macro quality traits	Drivers	Resources allocated for improving quality traits
Oil (Human use)	Increased oleic (C18:1)	Oilseed crusher	Large
Oil (Frying stability)	Lower linolenic (C18:3)	Food companies	
Meal (stockfeed)	Low glucosinolates	Stockfeed Industry	
Health	Long chain omega-3 fatty acids. Increased DHA	Consumers	Unknown

As Australia embraced the value of olive oil, the canola industry realised an opportunity to develop an oil with health-giving benefits similar to olive oil. The aim was to increase oleic acid levels and reduce the level of saturated fatty acids. Recently, there have been reports on the development of germplasm with an increase in omega-3 fatty acids with DHA levels similar to those found in fish to directly target the health market (Media bulletin, 2014).

Pulses

Of all the grains consumed by humans, pulses are still an untapped resource for enhanced human nutrition and wellbeing. Pulses, including the two, I referred to earlier; lentils and field peas are widely consumed outside Australia, their consumption by Australian residents is still quite small by comparison. We know that pulses are high in protein, carbohydrates, fibre and secondary plant metabolites with reputed bioactive properties (Rochfort and Panozzo, 2007).

Pulse quality traits and breeding objectives can be segmented into four groups as outlined in Table 4. These are physical seed characteristics, processing characteristics, macro-seed composition such as protein, carbohydrate and fibre; and compounds present in minor concentrations such as isoflavones, saponins, oligosaccharides and phytates. The segmentation of traits in Table 4, reflects the relative consumption with the majority of pulses used as a whole seed or as a split product. The four sectors also align with resources allocated to the development of a new variety.

To date most of the breeding objectives for pulses have been based on improving seed size, shape and colour, as these traits are the basis for trading within the Indian sub-continent. In addition as the majority of pulses are dehulled and split, the second most important breeding objective centres on dehulling and splitting, hydration and cooking time. The combination of optimising the physical seed traits and improving processing characteristics accounts for the majority of the resources allocated to improve quality traits in a new variety.

Table 4: Pulse Grains

Product	Macro quality traits	Drivers	Resources allocated for improving quality traits
Whole grain	Seed size, shape and colour	Traditional consumers *Indian sub-continent*	Large
Processed grain Splits products (dahl) Flour (besan)	Dehulling/splitting Split colour, Cooking time	Traditional consumers *Indian sub-continent*	
Seed composition "Food"	Starch Protein Fibre	Non-traditional consumers *Western consumers*	Small
Seed Composition "Health"	Bioactive compounds *(for example)* Isoflavones Phytosterols Saponins Oligosaccharides Phytates	Non-traditional consumers *Western consumers*	

There is no disputing that seed composition such as proteins and carbohydrates will affect cooking traits. However, in most cases, as food is prepared within a household, the cooking process can be adjusted to compensate for any variation in grain composition. Two components of pulse quality as outlined in Table 4, worthy of further investigation and development are associated with seed composition. These are macro-compounds such as protein, carbohydrates and fibre which can be used particularly for non-traditional food products and opportunities exist for developing protein isolates which don't have the negative association of protein isolates derived from dairy, soy or wheat. In addition, bioactive compounds including isoflavones, oligosaccharides and phytosterols which are of interest for their purported health benefits present additional prospects for pulses.

All of the traits I have described for each grain type are controlled by multiple genes and therefore by understanding the plant genome and their biochemistry, researchers are able to make a stepwise improvement in plant breeding or genetic selection. Moreover, we also know there are significant interactions with environmental conditions which alter the expression of a particular trait and this can have a positive or negative effect.

Grain quality and nutrition in a changing environment

There is no disputing that carbon dioxide levels in the atmosphere have steadily increased since the commencement of industrialisation and it has been estimated that levels of carbon dioxide will reach 550 ppm by the year 2050 (IPCC, 2007). To investigate the effect the effect of elevated carbon dioxide in the atmosphere on crop growth, the Australian Grains Free Atmospheric Carbon Enrichment facility (AGFACE) was established at Horsham, Victoria with funding from the State Government of Victorian, the Grains Research and Development Corporation, the Commonwealth Government and the University of Melbourne. The infrastructure was designed so that 550 ppm of carbon dioxide could be applied throughout the growth stages of the crop and the response to elevated carbon dioxide investigated in a diverse range of experiments (Mollah et al.,2009). The facility undertakes research projects supported by Melbourne University, the Federal Department of Agriculture, Australian Research Council, the Victorian State Government and the Grains Research and Development Corporation (PICCC, 2015).

Based on data from Victorian AGFACE, we have been able to confirm that elevated carbon dioxide conditions increase plant biomass and grain yields of wheat. Of significance for the grains industry, the protein percentage in the grain decreased by five to seven percent relative to the ambient CO_2 treatment. This may necessitate increased use of fertilisers to maintain the protein levels in the future. We have demonstrated that elevated carbon dioxide also alters protein composition and in particular the synthesis of glutenin and gliadin proteins which are important for optimum dough rheology. In addition we have reported on the deleterious effect on baking quality and reduced bread volume (Panozzo et al., 2014).

The implications for human nutrition are also significant. Myers et al. (2014) reported in the journal Nature, using data derived from the Victorian AGFACE facility and elsewhere, that elevated carbon dioxide conditions resulted in a significant decrease of approximately 10% in zinc, and 5% in iron and, phytate in wheat. The implications are significant as further modelling studies undertaken by Myers et al., (2015) suggest that the countries that will be most at risk of zinc deficiency as a result of elevated levels of carbon dioxide will be the African continent as well as the Indian subcontinent and the Middle-East.

Concluding remarks

I have highlighted the important work that is undertaken by plant breeding programs in ensuring that every new variety is adaptable within a constantly changing Australian environment.

It is important that each variety is fit for purpose and extensive testing is undertaken to ensure this is the case for both the domestic market and for highly competitive export markets. It is clear that for macro components of grain, their effect on product quality, particularly for cereal grains and oilseeds, is clearly understood and with the advancement of new genomic and phenomic technologies, significant gains in tackling more complex traits will be possible in the future.

With the acceleration of lifestyle diseases and the apparent increase in cereal-based allergies, further research in developing new varieties to assist in overcoming these issues will become more important.

The promotion of pulses as a nutritious source of protein, carbohydrates and fibre and other minor components in western diets needs to be ongoing.

With climate change and increasing climate variability ensuring new varieties combine grain quality traits and nutritional composition to feed the world will become paramount particularly as demonstrated in the literature that human nutrition may be compromised.

Much of the research involving food for human nutrition or wellbeing has investigated a particular component of the grain in isolation, and looked at the biochemical response. For example, the effect of β-glucans to reduce plasma LDL cholesterol levels. This reductionist approach is often used in science to investigate cause and effect, however grains should be regarded as a matrix containing a range of bioactive compounds. Each will have a direct or interactive effect on our wellbeing. Future research therefore needs to be holistic and consider the effects of more than one component. Similarly, medical science needs to work more closely with applied sciences such as plant improvement so that we can ensure ongoing food and nutritional security for the world.

References

Media Bulletin (2014) ***Sustainable DHA omega-3 canola closer to reality***. http://www.nufarm.com/assets/26570/1/Omega-3collaborationupdatereleaseJan2014Final.pdf

Rochfort, S. and Panozzo, J.F. (2007). Phytochemicals for health, the role of pulses. ***Journal of Agriculture and Food Chemistry***, 55: (20), 7981-7994

IPCC Core Writing Team: PauchauriI, R.K. and Reisinger, A.(2007). ***Climate Change 2007. Synthesis Report***. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC

Primary Industries Climate Challenges Centre: ***The Australian Grains Free Air Carbon Dioxide Enrichment Facility (AGFACE***) (2015) http://www.piccc.org.au/research/project/252

Mollah, M., Norton, R., Huzzey, J. (2009) Australian Grains Free Air Carbon Enrichment (AGFACE) facility: design and performance. ***Crop and Pasture Science*** 60: 697-707 http://dx.doi.org/10.10171.CP08354

Panozzo J.F., Walker, C.K., Partington, D.L., Neumann, N.C., Tausz, M., Seneweera, S. and Fitzgerald. G.J. (2014) Elevated levels of carbon dioxide changes protein concentration and composition and, compromises baking quality. A FACE study. ***Journal of Cereal Science*** 60: 461-470 http://dx.doi.org/10.1016/j.jcs.2014.08.011

Myers, S.S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A.D.B., Bloom, A.J., Carlise, E., Dietterich, L.H., Fitzgerald, G., Hasegawa, T., Holbrook, N.M., Nelson, R.L., Ottman, M.J., Raboy, V., Sakai, H., Sartor, K.A., Schwartz, J., Seneweera, S., Tausz, M. and Usui, Y. (2014) Increasing CO_2 threatens human nutrition. ***Nature*** 510: 139-143, http://dx.doi.org/10.1038/nature13179

Myers, S.S., Wessels, K.R., Zanobetti, A. and Schwartz, J. (2015) Effect of increased concentrations of atmospheric carbon dioxide on the global threat of zinc deficiency: a modelling study. ***The Lancet***. 1-7. http://dx.doi.org/10.1016/52214-109x(15)00093-5