Proceedings of the Perennial
Artisan Grains Workshop

Edited by Matthew T. Newell
August 2021
Foreword

Modern annual grain production systems supply 70% of the calories required to meet human dietary needs and globally occupy a similar proportion of agricultural land. More than 50% of consumption is supplied by just three crops – corn (Zea maize), rice (Oryza sativa) and wheat (Triticum aestivum). Modern agriculture’s ability to meet the increasing demand for products has hinged on simplifying traditional agroecosystems, by growing annual crops as monocultures with increased yields through using external inputs. The intensification of agricultural production has been successful in meeting global food demand by increasing productivity per unit area. However, intensive crop production has led to substantial soil degradation associated with the run-down of organic matter and disruption of the hydrological balance within landscapes by replacing endemic perennial-based vegetation with annual crop and pasture systems. Developing diverse grain production systems based on perennial plants offers opportunity to reverse the ongoing degradation of crop lands and diversify the range of crops used for food. Moreover, perennial grains offer an unexplored opportunity to develop novel food products from new grains possessing a range of attributes difficult to source in commercial cereal cultivars.

This project aimed to characterise the milling and end-use functional characteristics for a number of perennial cereal candidates that have shown potential for Australian environments. There is a growing movement of artisan bakers catering for the increasingly discerning Australian consumer, who is no longer satisfied with products derived from industrial white flour produced from commodity grains harvested on a large scale. This market is sensitive to the negative health outcomes from products derived from refined white flour, as well as the environmental sustainability of food production systems. Developing perennial cereal grains for this market shows promise.

The project culminated in a workshop, held at Cowra NSW from 15-17 June 2021. This event brought together national and international scientists working in perennial grains research, as well as industry specialists from across the milling, baking, brewing, processing and grain marketing sectors. There were 23 delegates who attended the workshop in person from across these groups. International guest speakers presented to the audience via a video conference platform, due to travel restrictions imposed by COVID-19. A further 17 participants from within Australia, the United States of America, Italy and New Zealand engaged in the workshop through a live stream of the event.

This report has been produced as part of AgriFutures Australia’s Emerging Industries Program. It is an addition to our diverse range of research publications and forms part of Arena 4, which focuses on new industries with high growth potential. Emerging animal and plant industries play an important part in the Australian agricultural landscape. They contribute to the national economy and they will be key to meeting changing global food demands. Most of AgriFutures Australia’s publications are available for viewing, free download or purchase online at www.agrifutures.com.au.

Michael Beer
General Manager Business Development
AgriFutures Australia
Acknowledgments

The workshop organising committee of Matthew Newell, Richard Hayes, David Monks, Kathryn Egerton-Warburton, Sarah Baker, Katrina Sinclair, Mark Evans and Daren Fahey would like to thank the industry partners for their time and efforts in testing a range of perennial grain material in their businesses. The range and quality of products on display was testament to their passion and commitment to their craft.

The committee also acknowledges the efforts made by international presenters from differing times zones to join the workshop via the online platform. Their contributions, despite the restrictions caused by COVID-19, were invaluable.
Contents

Foreword ................................................................................................................................................. ii
Acknowledgments .................................................................................................................................. iii
Executive summary ................................................................................................................................. v
Industry partners ..................................................................................................................................... 1
Workshop program ................................................................................................................................. 4
Is the future of agriculture perennial ................................................................................................... 6
   Tim Crews
Multifunctional perennial grain systems for Australia .......................................................................... 15
   Matthew T. Newell, Richard C. Hayes and Gordon Refshauge
Wheat x wheatgrass perennial grains’ introduction to contemporary agroecosystems ................... 21
   Robin Morgan and Stephen Jones
Agronomic, technological and nutritional characterisation of selected perennial wheat lines grown in Italy ............................................................................................................................................... 27
   Laura Gazza, Elena Galassi and Pierino Cacciatori
Hedonic exploration of sensory attributes from sourdough loaves made from perennial wheat ...... 33
   Matthew T. Newell, Sarah Baker, Katrina Sinclair, Richard C. Hayes and Emily Salkeld
Artisan baker assessment of sourdough loaves using perennial cereals: A preliminary study ......... 40
   Katrina Sinclair, Sarah J. Baker, Matthew T. Newell and Richard C. Hayes
A brewer’s assessment of beer made using perennial grains ............................................................ 47
   Sarah J. Baker, Katrina Sinclair, Richard C. Hayes and Matthew T. Newell
Assessing the potential of perennial cereals in processing food products ........................................ 50
   Sarah J. Baker, Katrina Sinclair, Richard C. Hayes and Matthew T. Newell
The effects of growing conditions on grain quality characteristics and functionality of Australian-grown perennial wheat ...................................................................................................................... 55
   Ke Hong Tang, Annie Riaz, Denise Pleming, Matthew Newell, Matthew Wilson, Richard Hayes, Chris Blanchard and Beth Penrose
Market failure in the Australian pasture seed supply chain and implications for perennial grains .. 62
   Richard C. Hayes
Development and commercialisation of specialty grains: Lessons from gluten-free barley and high fibre wheat and barley ................................................................................................................... 69
   Philip Larkin and Crispin Howitt
Certified Australian Sustainable Produce and growing a niche market for perennial grains.......... 76
   Miriam Neilson
Appendix 1: Perennial artisan grains – user survey .............................................................................. 81
Appendix 2: Perennial wheat sensory survey ........................................................................................ 89
Executive summary

Modern annual grain production systems supply 70% of the calories required to meet human dietary needs and globally occupy a similar proportion of agricultural land. More than 50% of consumption is supplied by just three crops – corn (*Zea mays*), rice (*Oryza sativa*) and wheat (*Triticum aestivum*). Modern agriculture’s ability to meet the increasing demand for products has hinged on simplifying traditional agroecosystems, by growing annual crops as monocultures with increased yields through using external inputs. The intensification of agricultural production has been successful in meeting global food demand by increasing productivity per unit area. However, intensive crop production has led to substantial soil degradation associated with the run-down of organic matter and disruption of the hydrological balance within landscapes by replacing endemic perennial-based vegetation with annual crop and pasture systems. Developing diverse grain production systems based on perennial plants offers opportunity to reverse the ongoing degradation of crop lands and diversify the range of crops used for food. Moreover, perennial grains offer an unexplored opportunity to develop novel food products from new grains possessing a range of attributes difficult to source in commercial cereal cultivars.

AgriFutures Australia project PRJ-01227, *Assessing artisan perennial wheat material as a new food crop*, was funded by AgriFutures Australia through their Emerging Industries Program. It aimed to characterise the milling and end-use functional characteristics for a number of perennial cereal candidates that have shown potential for Australian environments. There is a growing movement of artisan bakers catering for the increasingly discerning Australian consumer, who is no longer satisfied with products derived from industrial white flour produced from commodity grains harvested on a large scale. This market is sensitive to the negative health outcomes from products derived from refined white flour, as well as the environmental sustainability of food production systems. Developing perennial cereal grains for this market shows promise.

The project culminated in a workshop, held at Cowra NSW from 15-17 June 2021. This event brought together national and international scientists working in perennial grains research, as well as industry specialists from across the milling, baking, brewing, processing and grain marketing sectors. There were 23 delegates who attended the workshop in person from across these groups. International guest speakers presented to the audience via a video conference platform, due to travel restrictions imposed by COVID-19. A further 17 participants from within Australia, the United States of America, Italy and New Zealand engaged in the workshop through a live stream of the event.

Prior to the workshop, samples of eight perennial cereal grains and a commercial wheat cultivar were sent to the industry participants for testing in their business. These included six hybrid perennial wheat breeding lines, produced from crossing annual wheat cultivars with perennial wheatgrass relatives, including 11955, 235a, Ot-38, OK72, Summer 1 and 20238. Two further entries were perennial relatives of annual cereal grains undergoing *de novo* domestication, intermediate wheatgrass and mountain rye. Grain of all eight entries was produced at NSW Department of Primary Industries research facilities at Wagga Wagga and Cowra during 2020. Following harvest, cleaned grain was sent to the industry participants for small-scale commercial testing.

Presentations at the workshop on objective measures described the superior phytochemical profile in perennial cereal lines, increasing the number of health-promoting compounds. However, laboratory testing of these grains also highlighted altered functional properties of the perennial lines, compared to commercial wheat cultivars, due to chromosome additions from the wheatgrass parents. The changed rheological properties led to “mediocre” breadmaking performance among the perennial cereals, compared to commercial wheat cultivars under standard testing protocols. In contrast, the bakers, brewers and processors assembled at the workshop found high functional qualities among the same material, with a utility to form a range of products from bread, biscuits, pasta, beer and rolled grain items. The industry partners were highly experienced in the use of speciality grains (spelt, korshan, rye, etc.) for diversity and flavour. Through their experiential knowledge, adjustments are

Proceedings of the Perennial Artisan Grain Workshop, 15 – 17 June 2021, Cowra, Australia © 2021
made to the milling, dough-making and baking protocols to achieve the desired characteristics in the final product. Participants were surveyed as to the performance of each grain and whether particular grains would find a market in their business. For the artisan bakers, information was sought on the volume, external appearance, colour, crumb texture and flavour of sourdough loaves of bread. Each attribute was rated as “very good”, “good”, “acceptable” or “poor”. Similar attributes were rated for brewing and processing by the respective participants. The survey demonstrated that selected perennial cereal grains currently under agronomic evaluation in Australia can be utilised to produce a high-quality product. In assessing the overall performance, almost all bakers assessed Summer 1, mountain rye, 11955, 235a and OK72 as being “market ready”, rating well for external and internal loaf characteristics. The standout of the survey results was the performance of mountain rye. From the results, 100% of bakers rated mountain rye as “very good” for external appearance and loaf volume, while 75% of those surveyed rated mountain rye “very good” for colour, texture and flavour. Similarly, mountain rye was rated “good” in the brewing survey. For processing, although grain size was small, mountain rye produced a “good looking” rolled grain and had the “best malty distinctive flavour”. This was a surprising result as there has been no selection for grain quality attributes in this entry, which was developed as a forage for livestock. One baker commented:

“This [mountain rye] is my favourite of all the test flours. Exceeded my expectations.”

Perennial grain agriculture is transformational and will require a shift in the farming system, with the deployment of perennial grains as polycultures with other functional plant species. These diverse plant populations will play a role in increasing resource use efficiency and provide ecosystem services such as nutrient input, disease control and soil carbon accumulation, which tend to be disrupted under continuous annual crop monocultures. An ability to enunciate a strong ecological story and provenance of ingredients answers many questions with the customer base for artisanal products and is an important aspect of marketing. As one participant explained:

“We see perennial grain as a hopeful, more sustainable, financially, environmentally, holistic approach to growing food in this era of rapid climate change and a tool to sequester carbon.”

Inevitably there are challenges in developing new grains for niche markets. Perennial grain development is still in its infancy and requires further improvement to enable a consistent supply of grain to end users. It is important to have a good understanding of the end use capability of current material at an early stage, to guide future development. Through consultation across the supply chain, the workshop provided four key outcomes:

- Most perennial cereals displayed surprisingly good functional properties in a range of artisanal products and for larger scale processing of breakfast cereals.
- There was great enthusiasm amongst the industry participants around the opportunities provided by perennial grains and confidence that markets could be found for most lines in the near term, once sufficient quantities were available.
- All Industry participants expressed the importance of the ecological story and nutritional benefits behind perennial grains in marketing of novel products. This highlights the importance of developing genuine perennial material as a point of difference in the market.
- Mountain rye was a standout entry due to its functional grain attributes coupled with strong persistence. This was in contrast to the wheat x wheatgrass breeding lines presently available. This entry offers the best near-term option for commercial release as a perennial grain.

These outcomes provide further evidence of the importance perennial grains can have in the industry and lays a platform from which to continue developing this material for Australian conditions.
Industry partners

Jason Cotter

As the owner and operator of Tuerong Farm, a mixed farming and milling enterprise on the Mornington Peninsula, Jason grows and mills modern, heritage and ancient grains for direct sale to leading restaurants, bakeries and home-bakers.

Jason was recently awarded a Nuffield scholarship to research ways to restore nutrition, flavour and resilience in our grain systems, with a particular focus on genetics and processes.

Michael James

Michael grew up in Penzance, West Cornwall. Michael believes in supporting local farmers who are using sustainable agricultural methods that ensure soil health.

Previously of Melbourne’s Tivoli Road Bakery, Michael remains committed to bringing real bread to as many people as possible, both through his influence in the local grain economy and as a passionate educator.

Emily Salkeld

Operates Small World Bakery with her husband Chris Duffy at Langhorne Ck SA. They are working to revive a local grain economy by growing out new generation historic cereal lines, stone milling and baking sourdough loaves.

Small World Bakery is always sharing experiences and connecting people with each other to strengthen an alternative industry for small scale businesses.

Kit Carpenter and Guy Miech

Kit is the Culinary Curator at Three Mills. His background in Anthropology and then traveling as a fine dining chef turned baker has given him a unique insight into global food concerns. Guy came to baking from the IT industry and runs the in-house sourdough development at Three Mills Bakery.

Together they are the progressive R&D wing of Three Mills Bakery looking to marry the quality and care of artisanry with a need to increase scale to push the industry forward.
John Pitcher and Mark Kelly

John is Technical Leader Australia at Cereal Partners Worldwide. John and Mark are technical specialist from the Wahgunyah R&D Pilot Plant facility, Victoria. Their deep understanding of the nutritional qualities and functional attributes of ingredients has allowed the development of many new products.

Topher Boehm

Topher Boehm is head brewer and co-founder of Wildflower Brewing & Blending. Wildflower focuses on fermenting beers with a mixed house culture of brewer’s yeast combined with wild yeast and bacteria foraged from New South Wales.

Topher has travelled extensively in Europe and Nth America to develop skills required to produce a range of wild, mixed fermentation beers.

Ian Lowe

Ian has studied the science of fermentation for the past 20-plus years and worked in the restaurant trade in New York, before moving to Australia.

He now lives and works in Tasmania, running Apiece Bakery.

His baking knowledge is invaluable and an inspiration to others in the industry.

Cesare Salemi

A third-generation baker and founder of Dust Bakehouse, Cesare is a pioneer baker and miller, international consultant and speaker, and entrepreneur living in Sydney. Ces has spent more than five years working with Australian farmers to regenerate rare heritage grains for use in baking, with vision to restore a local sustainable grain economy.

Cesare co-founded GrAiNZ, a community of the finest bakers and bread aficionados in Australia and New Zealand. The yearly gathering of this group has a global influence connecting participants along the supply chain to exchange knowledge and comradeship in an inclusive environment.
Wendy, Kim and Dougal Muffet

The Muffet family are fourth generation farmers and operate Girragirria Green Living in Forbes NSW. The property includes an eco-retreat, where guests can pick their own organic food and join in sourdough and fermented food workshops with other locals.

Wendy and Kim have been instrumental in developing the “Grazing down the Lachlan” food tourism event. They are joint winners of Citizen of the Year Honour (2020) for their tireless volunteering in the local community.
Workshop program

Welcome by Dept of Primary Industries and AgriFutures Australia

Dougal Gordon and Laura Skipworth

Session 1 – Perennial grains - vision, breeding and research

Chair: Mark Evans (NSW DPI)

Is the future of agriculture perennial? Tim Crews (The Land Institute)

Multi-functional perennial grain systems for Australia Matthew Newell (NSW DPI)

The Land Institute perennial wheat breeding program Shuwen Wang (TLI)

A place for perennial grains in contemporary agro-ecosystems Robin Morgan (Washington State University)

Session 2 – Perennial grain performance

Chair: Michael Southan (Australian Olive Association)

Agronomic, technical and nutritional properties of perennial wheat Laura Gazza (Council for Agricultural Research and Economics – Italy)

CSIRO bake lab results of perennial grains and nutrient dense black rice Philip Larkin (CSIRO)

Tuerong Farm small scale milling of perennial grains Jason Cotter

Baking with perennial grain flour Michael James

Small World Bakery test results Emily Salkeld

Three Mills Bakery test results Kit Carpenter and Guy Miech

Session 3 – Perennial grain performance (cont.)

Perennial grains for breakfast cereals and snacks John Pitcher (Uncle Toby’s)

Wildflower Brewing and Blending test results Topher Boehm

Implications of baking with perennial grains Ian Lowe (Apiece Bakery)

Beer and bread tasting and discussion (group presentation) Chair: Darren Fahey (NSW DPI)

Cowra DPI research station tour Gordon Refshauge (NSW DPI)

Workshop dinner – Opportunities for perennial grains Cesare Salemi (Dust Bakehouse/GrAiNZ)
Session 4 – Marketing and supply chains for perennial grains  
Chair: Darren Fahey (NSW DPI)

Environmental effects on grain quality of perennial grains  
Chris Blanchard (Graham Centre)

Market failures – Lessons from the pasture seed industry  
Richard Hayes (NSW DPI)

Development and marketing of specialty grains: Lessons from gluten-free barley and high fibre wheat and barley  
Philip Larkin (CSIRO)

Certified Australian Sustainable Products and growing a niche market for perennial grains  
Miriam Neilson (Southern Cross Agricultural Exports)

Market access in emerging small grain industries  
Laura Skipworth (AgriFutures Australia)

What’s missing in current perennial grain material? (group discussion)  
Chair: Philip Larkin (CSIRO)
Is the future of agriculture perennial?

Tim Crews

The Land Institute, 2440 E. Water Well Road, Salina, KS, 67401, landinstitute.org, email: crews@landinstitute.org

Abstract

The farming of annual grains is deeply embedded in most human cultures. Yet, in spite of impressive levels of productivity, most annual cropping systems experience losses of soil organic matter, of nutrients, and soil itself, relative to the perennial native vegetation that preceded agriculture. In 1980, Wes Jackson published New Roots for Agriculture in which he explored the ecological and social rationale for developing a new grain agriculture that features perenniality and diversity—two key characteristics of virtually all natural, land-based ecosystems. Decades later researchers at The Land Institute in Salina, Kansas USA, and a global network of partners are working to develop perennial grain crops.

Two distinct but overlapping approaches to create perennial grain crops have shown genuine progress; de novo domestication, in which breeders choose promising wild perennial species and breed them into cultivars through repeated cycles of directed sexual selection, and wide hybridisation, which involves the crossing of existing elite annual crops with wild perennial relatives. silphium, sainfoin and Kernza® are perennial grain crops in the de novo domestication pipeline, while perennial versions of wheat, sorghum and rice are examples of wide hybrid crosses in the breeding pipeline. Both perennial rice and Kernza have had commercial cultivars released and there is great interest among bakers, brewers and other food innovators in developing products from a sustainably produced grain such as Kernza.

Concurrent to the breeding program is the development of the farming system that will see the deployment of perennial grains as polycultures with other functional plant species. These diverse plant populations will play a role in increasing resource use efficiency and provide ecosystem services such as nutrient input, disease control and organic matter accumulation, which tend to be disrupted under continuous annual monocultures. While perennial grains are a long-term prospect, the evidence suggests that the future of agriculture can be perennial, and it will be worth the wait.

Key words

Perennial grain polycultures, ecological intensification, roots, Kernza®, de novo domestication, wide hybridisation

Introduction

In the second half of the 20th century, Wes Jackson became well-known for his conviction that a truly sustainable agriculture will be directly keyed to nature (Jackson 1984). He contended that all the natural ecosystems of the earth are many times more complex than our most elaborate agricultural ecosystem, and that those natural ecosystems are the most appropriate and useful standard with which to judge the success or failure of our food producing ecosystem. When Jackson compared the ecological status of row crop agriculture to natural ecosystems like the tallgrass prairie, it was clear that agriculture was profoundly underperforming (Jackson 1980). Soils continued to erode well beyond replacement rates, nutrients were running off or leaking into waterways, and toxins were
being used to combat plant and animal pests, while poisoning the ecosphere as a whole. To explain the pervasiveness of these and other shortcomings of agriculture, Jackson held up two defining characteristics that contributed to the complexity and integrity of virtually all natural, terrestrial ecosystems and yet were largely absent from fields of grain the world over – perenniality and diversity (Jackson 1980). Diverse, perennial vegetation dominates the productivity of almost all natural terrestrial ecosystems (Crews et al. 2017), and it was under the influence of these ecosystems—grasslands, forests, savannahs—that the planet’s soils have developed. Annual row crop agriculture has, to a tremendous extent, depended on the soil capital accumulated under the preceding natural ecosystems.

It was against this backdrop that Jackson proposed that a wide range of problems in agriculture would be addressed by redesigning the ecosystem itself to more closely resemble the structure and function of the natural ecosystem it replaced (Jackson 1980). Perenniality and diversity were central components of “The Marriage of Ecology and Agriculture” (Jackson 1990). This wholesale re-envisioning of the crops and cropping arrangements that occupy some 70% of cultivated land, or 8.4% of all land, was unprecedented. Diversifying agriculture was not itself revolutionary given that most pre-industrial agricultural landscapes were planted with a greater number of genotypes or species compared with today. Cropping systems became much more taxonomically simple when mechanisation was widely adopted, and N fixed through the Haber-Bosch process made legume rotations and intercrops unnecessary. Nevertheless, Jackson was clear in his view that farmers’ reliance on purchased inputs of pesticides and nutrients was closely tied to reductions in biodiversity across the landscape. It was Jackson’s proposal to develop perennial grain crops—cereals, pulses and oilseeds—and then grow them in diverse assemblies that caught the attention of farmers, academic researchers and the public at large. This vision of grain agriculture transforming annual monocultures to perennial polycultures propelled a research effort that has now grown to include researchers at over 60 institutions around the world in over 15 countries (LandInstitute.org).

**Background**

There are many hypotheses as to why humans exclusively domesticated annual rather than perennial grasses as cereal crops (Van Tassel et al. 2010). Arguably the most parsimonious explanation lies in the process of crop evolution itself. The transformation of a wild species which produces lots of small seeds that disperse far and wide, to crops that produce large seeds on non-shattering heads which can be harvested, requires countless cycles of human-directed selection. Crop evolution *only* takes place when the cycle of sowing, cross-pollinating and harvesting happens repeatedly (Harlen 1995). Early Neolithic proto-farmers likely knew that perennials re-grew, making it unnecessary to re-plant their seeds to obtain a harvest in the subsequent year (Crews, in press). In fact, the amount of muscle energy required to kill perennials in order to clear the space to re-sow them would have been substantial, steering them towards annual counterparts that conveniently died on their own. Simply put, the evolutionary pathway to large-seeded grasses was most easily charted with annuals. It appears self-evident that the choice had nothing to do with soil health, nutrient retention or other cornerstones of ecological sustainability. By the time early agricultural societies experienced stress or even collapse induced by soil erosion and degradation (Hillel 1991, Montgomery 2007), it was too late, humans had become irreversibility dependent on the calories produced by domesticated grains.

Telescoping ahead to the present day, a majority of calories that feed nearly eight billion humans, either through direct consumption or livestock feed, come from annual grains (Monfreda et al. 2008). In some respects, the sheer growth in the human population over the last millennium could be viewed as a sign that humans took the “right” path with the annual grain ecosystem. However, it has become difficult to find an assessment of regional or global agricultural sustainability or resilience that is optimistic, while there are many that express grave concern, especially about the health of soils. In 2019, the IPCC issued a special report on Climate Change and Land which stated that soil loss from conventional agriculture was exceeding soil formation by >2 orders of magnitude. No-till strategies
clearly reduce soil loss from erosion, but it can still exceed formation by >1 order of magnitude (Nearing et al. 2017). Even in regions where large investments have been made in conducting scientific research to understand erosion hazards, and subsequent investments made in public programs to implement soil conservation strategies, wind and water erosion continue at unacceptable levels. A recent study published in the Proceedings of the National Academy of Science (USA) details how ~35% of corn belt soils in the Midwest USA have lost most to all of their highly fertile A horizons to erosion (Thaler et al. 2021). While technical fixes such as conservation tillage or terracing in annual crops have reduced but failed to sufficiently curb soil erosion, the evidence that perennial roots and vegetative cover can not only protect soil, but build soils is robust (Gyssels et al. 2005, Nearing et al. 2017).

Arguably, erosion is the most consequential form of soil degradation. However, the lack of perennial roots in arable agroecosystems also disrupts nutrient retention. Rockström, Steffan and others (2009, 2015) argue that contemporary flows of nitrogen and phosphorus through terrestrial and aquatic ecosystems critically exceed what the ecosphere can process. The environmental consequences of exceeding N and P planetary boundaries include eutrophication of freshwater and marine ecosystems (Sharpley and Rekolainen 1997, Elser et al. 2007), the formation of more than 400 hypoxic (dead) zones in seas or oceans around the world (Diaz and Rosenberg 2008), increased emission of the potent greenhouse gas nitrous oxide, fertilisation of downwind ecosystems, and acidification of agricultural soils (Helyar 1990, Galloway et al.). Tracing the N- and P-containing molecules responsible for these impacts back to where they originated, it is evident that globally, annual croplands are by far the most important source although there are other hotspots such as animal feedlots (Mallin and Cahoon 2003). To understand why this is the case, it is helpful to view annual croplands as a type of ecosystem in a continuum of ecosystems at different stages of development that have predictable behaviours. Ecologists have long recognized the dynamics of nutrient retention and loss that occur at different stages of ecosystem development or succession (Gorham et al. 1979). In ecology, succession describes directional changes in the composition of biological communities and their ecosystem processes through time (Odum 1969). Primary succession is the development of an ecosystem starting from the beginning – the colonisation of newly exposed rock or newly deposited sediment by plants, microbes and other organisms. Secondary succession occurs following disturbance to an already existing ecosystem by fire, drought, flood, or any other force that disrupts or eliminates the dominant plant/organisnal community (Whittaker 1975). Farmers actively manage a number of agents to re-set farmlands back to early stages of secondary succession, which is to say freshly tilled fields ready for planting. With the harnessing of draft animal power and then fossil fuels, the force of the plough and more recently herbicides have become the agents of choice to arrest farmlands in a perpetual stage of early secondary succession (Crews and others 2016; Smil 2018). The introduction of perennial grain crops has the potential to shift agriculture to a later successional stage and in doing so re-build soil health (Crews et al. 2016). Farmers already utilise perennial pasture rotations to repair soil and in the near-term, perennial grains in early stages of development may perform as viable substitutes (Ryan et al. 2018). Once multiple perennial grains are fully developed, grain agriculture as a whole could more permanently shift to a later stage of succession where soils accumulate organic matter and develop structure similar to natural systems.

Another form of soil degradation that is strongly driven by the temporal and spatial reduction of roots is the almost universal decline in soil organic matter in annual grain ecosystems. This decline occurs because annual crops contribute much less organic matter to the soil, especially in the form of roots, and they sustain higher rates of loss of organic matter as CO₂ from microbial respiration (Crews and Rumsey 2017; Reicosky and Janzen 2019). Being composed predominantly of perennial species, the vegetation of natural ecosystems allocates some 50-68 percent of net primary productivity (NPP) below ground (Saugier et al. 2001). In contrast, the below-ground allocation of NPP in annual crops is between 15-25 percent (Goudriaan et al. 2001; Whalen and Sampedro 2009). Moreover, recent research suggests that roots play a greater role in the formation of soil organic matter than above-ground residues. Jackson and colleagues (2017) reviewed 16 studies using primarily isotopic approaches to compare contributions to soil organic matter from above-ground and below-ground plant inputs; they found that the average and median below-ground inputs retained as soil organic
matter were 45 and 39 percent, respectively, whereas above-ground inputs retained were 8.3 and 6.6 percent.

**Breeding new perennial “hardware”**

There is widespread recognition that planting diverse perennial vegetation is one of the most dependable means for improving soil health and correcting the ecosystem disservices associated with annual grain crops (Crews et al. 2018; Sprunger et al. 2020; Ledo et al. 2020; Sanford et al. 2021). The rationale for developing perennial cereal, pulse and oilseed crops is very compelling, and yet the time and sustained resources required for breeding new perennial crops is sobering. Nevertheless, considerable progress has been made on a number of species over the last two decades (Table 1), and interest in collaborating on long-term breeding projects continues to expand. Two basic approaches are currently employed to develop new perennial grain crops—*de novo* or direct domestication and wide hybridisation. Domestication projects have traditionally involved repeated cycles of crop production, phenotype evaluation, selection of individual genotypes that present desirable traits, intermating of selected individuals and seed collection (Van Tassel and DeHaan 2014). This process has been accelerated with molecular tools such as marker assisted selection (MAS) and genomic selection that have become increasingly affordable in the last decade. Kernza is the grain with the most developed genomic selection model, allowing for a complete selection cycle to take place in one year (Crain et al. 2021a; Crain et al. 2021b). Gene editing is also being evaluated as an approach to induce targeted mutations that would allow identification of genes that control key domestication traits such as non-shattering (DeHaan et al. 2020). Another novel approach to accelerate breeding efforts that is currently under evaluation is phenomic selection, an indirect, low-cost approach that uses models based on variation in specific phenotypic traits to achieve results similar to those made possible by genomic selection (Rincent et al. 2018).

The second approach to developing perennials is to cross existing high-yielding annual grains with related, usually wild, perennial species either in the same genus or tribe with the goal of introgressing the genes that confer perennialism into the annual species. Wide hybridisation is attractive because, if successful, the new hybrid species can largely inherit highly developed traits such as yield and end-use quality from the already domesticated annual parent. This is exactly what has happened in a perennial breeding grain program in the province of Yunnan, China, where the annual rice variety, *Oryza sativa*, was crossed with a perennial relative, *Oryza longistaminata*, to create a high yielding perennial rice with excellent grain quality (Huang et al. 2018). In many cases, however, challenges arise when the chromosome sets (genomes) or number of chromosome sets (ploidy level) in the annual and perennial parents do not match and/or do not recombine during meiosis. But these challenges can be managed as has been shown with the recent discovery of diploid and triploid perennial sorghum mutants that more readily cross with diploid annual sorghum than the original tetraploid perennial *Sorghum halepense* used in the original cross to develop perennial sorghum.
Table 1. Perennial grain crops in the breeding pipeline

<table>
<thead>
<tr>
<th>Perennial crop</th>
<th>Breeding strategy</th>
<th>Family and functional group</th>
<th>Ecological intensification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kernza® grain from intermediate wheatgrass <em>Thinopyrum intermedium</em></td>
<td>Domestication</td>
<td>Poaceae Cool season (C₃) grass</td>
<td>Extensive fine root system very effective at retaining nutrients.</td>
</tr>
<tr>
<td>Kura clover intercrop <em>Trifolium ambiguum</em></td>
<td>Domestication</td>
<td>Fabaceae Legume forb</td>
<td>Versatile, living mulch that fixes N and suppresses weeds.</td>
</tr>
<tr>
<td>Rice grain <em>Oryza spp. x Oryza longistaminata</em></td>
<td>Wide hybridisation</td>
<td>Poaceae Cool season (C₃) grass</td>
<td>Potentially lower flooding requirements, future upland hybrids reduce erosion.</td>
</tr>
<tr>
<td>Sainfoin pulse <em>Onobrychis vicifolia</em></td>
<td>Domestication</td>
<td>Fabaceae Legume forb</td>
<td>Dual use, N-fixing grain-forage crop for semi-arid environments.</td>
</tr>
<tr>
<td>Silflower oilseed <em>Silphium integrifolium</em></td>
<td>Domestication</td>
<td>Asteraceae Aster forb</td>
<td>Avoids drought by accessing groundwater with deep tap roots.</td>
</tr>
<tr>
<td>Sorghum grain <em>Sorghum bicolor x Sorghum halepense</em></td>
<td>Wide hybridisation</td>
<td>Poaceae Warm season (C₄) grass</td>
<td>Hosts endophytic nitrogen fixing bacteria.</td>
</tr>
<tr>
<td>Wheat grain <em>Triticum durum x Thinopyrum intermedium</em></td>
<td>Wide hybridisation</td>
<td>Poaceae Cool season (C₃) grass</td>
<td>Resistant to fusarium head blight and bacterial leaf streak.</td>
</tr>
</tbody>
</table>

Assembling functional agroecosystems

Given the progress that has been achieved over the last two decades in perennial grain breeding programs, it is now possible to begin working with the new crop “hardware” to create cropping systems including polycultures that maximize ecological intensification. Combining cereals with legumes has been a practice throughout the history of annual agriculture, and the model is equally compelling in new perennial systems (Crews et al. 2016). An intercrop experiment was established in Salina, Kansas USA to examine combinations of Kernza and alfalfa (*Medicago sativa*) over five years. Treatments included fertilized and unfertilized Kernza monoculture plots planted at two row spacings (38 and 76 cm), and an Kernza-alfalfa intercrop treatment planted in alternating 38cm rows. In year-three of the study, biomass yields of the two high-density Kernza monoculture plots...
planted on 38cm row spacings, KK & KK+N, were the lowest and highest, respectively, of all plots measured (Figure 1a). Nitrogen was clearly a limiting factor at this planting density. Differences in biomass yields of Kernza planted on 76cm row spacings were not significant, yet the mean yield of the Kernza-alfalfa (KA) treatment fell between unfertilized (K) and urea-amended (K+N) treatments. When the alfalfa biomass was included in the comparison, the KA intercrop biomass yield was equal to that of the KK+N treatment (Figure 1b). The results from this study suggest that 1) Kernza and alfalfa are not strongly competing for water, 2) alfalfa appears to be facilitating Kernza growth, presumably through contributions of biologically fixed N, and yet nitrogen limitation is not fully relaxed, 3) the KA-Kernza biomass yield was close to 2/3 of the KK+N yield at half the row spacing, suggesting intraspecific competition for some resource at the higher planting density (seeding rate per row was equal) (Crews et al. in review).

![Figure 1(a). Year 3 comparison of above ground Kernza biomass yields in treatments with two row spacings (K=76cm, KK=38cm). Urea-N was added at 75 kg ha⁻¹ in K+N plots, and 150 kg ha⁻¹ in KK+N plots. KA plots were planted in alternating Kernza, and alfalfa rows spaced at 38cm. (b) Includes alfalfa biomass yield in the KA plot (in green). Error bars = 1 S.E., bars with different letters are significantly different at p <0.05, Tukey HSD.](image)

Current cropping systems research at The Land Institute is focused on enhancing the synchrony of N derived from N fixation by alfalfa, and Kernza N requirements, especially during grain fill. One promising approach combines benefits of intercropping and rotating crops. Pure stands of alfalfa are grown for hay allowing the soil to accumulate a sizable pool of organic nitrogen. In summer of year 2 or 3, strips of alfalfa are terminated using an undercutter or herbicide (Figure 2a), and within two months, Kernza is sown into the strips, with rows of alfalfa remaining between newly established Kernza. When it is sown in late summer or early fall, Kernza generally produces a respectable harvest the following summer, typically about a month after the solstice in Kansas. The intercropped strips of alfalfa are mowed up to 4 times per year and left as mulch to maximize alfalfa productivity and thus fixed nitrogen inputs into the agroecosystem (Crews et al. 2016). A project is underway with Land Institute researchers and collaborators to develop an intercrop forage harvester that can remove the alfalfa from between the rows of Kernza for use as forage. Because the alfalfa is regularly cut, the Kernza is easily combined as it grows 40-60cm above the height of the alfalfa (Figure 2b).
Figure 2 (a). 60 cm strips of alfalfa terminated with an undercutter in a two-year field. Two 30 cm rows of Kernza were drilled in the strips within 45 days. (b) View from plot combine of Kernza being harvested from a Kernza-alfalfa rotational intercrop trial at The Land Institute.

Conclusion

Considerable progress has been made in developing what Wes Jackson imagined when he wrote *New Roots for Agriculture* in 1980. Two perennial grains are now being planted by farmers for commercial production. Perennial rice is being grown on > 8000 hectares in the Yunnan Province of China and Kernza is being grown on >800 hectares in the US. Moreover, interest in both of these crops is spreading rapidly with rice trials underway in Laos, Cambodia, Vietnam and Myanmar, and Kernza trials being established in France, Sweden, Denmark, Spain, The Czech Republic, Moldova and Siberia. Alfalfa and other legumes, including red clover (*Trifolium pratense*), sainfoin (*Onobrychis vicifolia*) and kura clover (*Trifolium ambiguum*) are being evaluated as companion species for Kernza by researchers at over 15 research universities in the US as well as Europe and Australia. These constitute very significant advances. And yet, in order to make the transition from the grain agriculture of today that owes its productivity to input intensification, to the perennial agriculture of tomorrow that will owe its productivity to ecological intensification, many more researchers will need to join in this work. Towards that end, a new organisational initiative is underway at The Land Institute called New Roots International. This initiative is being designed to advise and support new hubs of perennial research around the planet, and to invite more voices and expertise into this long-term effort to mentor, share and forge the path to a natural systems-inspired agriculture.

References


Crain J et al. (2021a) Genomic prediction enables rapid selection of high-performing genets in an intermediate wheatgrass breeding program. *The Plant Genome* e20080.

Crain J et al. (2021b) Development of whole-genome prediction models to increase the rate of genetic gain in intermediate wheatgrass (*Thinopyrum intermedium*) breeding. *The Plant Genome* e20089.

Crews TE et al. (2016) Going where no grains have gone before: From early to mid-succession. *Agriculture Ecosystems and Environment* 223, 223-238.


Rincent R et al. (2018) Phenomic selection is a low-cost and high-throughput method based on indirect predictions: proof of concept on wheat and poplar. *G3* 8, 3961-3972.


Sanford GR et al. (2021) Perenniality and diversity drive output stability and resilience in a 26-year cropping systems experiment. *Field Crops Research* 263, 108071.


Multifunctional perennial grain systems for Australia

Matthew T. Newell¹,³, Richard C. Hayes² and Gordon Refshauge¹

¹ NSW Department of Primary Industries, Agricultural Research and Advisory Station, Cowra, NSW 2794
² Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW 2650
³ Email: matt.newell@dpi.nsw.gov.au

Abstract

A multifunctional perennial grain polyculture is proposed to increase resource use efficiency and promote ecosystem services to sustain grain production over a longer term, compared with annual monoculture crops. Combinations of legumes and perennial cereals have proven successful in sustaining grain yields up to 2.0 t/ha/year. Grazing the vegetative phase of perennial wheat with an option for harvesting grain later in spring allows integration of cropping and grazing systems and increased productivity. Similar to some annual cereals, forage of perennial wheat is imbalanced in mineral content and may be unable to meet the requirements of high-producing classes of livestock. Recent research has examined the ability of different perennial wheat-legume combinations to balance mineral intake and mitigate risks of metabolic disorders in grazing ruminants as well as effects on meat quality. Results have shown that perennial wheat can be substituted for annual wheat in grazing systems with no detriment to meat production and eating quality of lambs and that combining legumes with the cereal forage can improve mineral intake and may reduce the need for supplementation.

While perennial wheat is the first crop to be investigated in Australia, other potential perennial grain options are also being evaluated. These include perennial sorghum which was grown for the first time in 2019. The perennial forage grass mountain rye is also receiving increased research attention due to its greater longevity compared with the hybrid wheat x wheatgrass lines. Here we review efforts in Australia to develop multipurpose perennial grain crops.

Key words: Perennial wheat, persistence, forage mineral content

Introduction

Modern Agriculture’s ability to meet the increasing demand for products has hinged on simplifying traditional agroecosystems and increased yields through the use of external energy inputs from highly condensed carbon (Bommarco et al. 2013). The intensification of agricultural production has been successful in meeting global food demand by increasing productivity per unit area. However, many landscapes are suffering from intensive crop production which has led to substantial soil degradation associated with the run-down of organic matter and disruption of the hydrological balance within landscapes by the replacement of endemic perennial-based vegetation with annual-based crop and pasture systems (Tilman et al. 2001). Developing perennial grain crops has the potential to offer a more environmentally sustainable grain production system into the future, reducing soil erosion, salinity, acidification, reduced labour and input costs as well as increased diversity in agricultural production through the use of perennial plants (Crews et al. 2018). With increasing demand for sustainably produced food, the successful integration of perennial grain into commercial cropping and food processing systems appears promising. Here we describe recent efforts at the Cowra Agricultural Research and Advisory Station, NSW, to progress perennial grain agricultural systems for Australian conditions.
Multifunctional agriculture

The focus for Australian perennial grain research since 2008 has been perennial wheat, derived from tall wheatgrass (*Thinopyrum ponticum*) or intermediate wheatgrass (*Th. intermedium*) crossed with various annual wheats (Hayes *et al.* 2012). As no locally adapted material is available, a range of international breeding material has been evaluated (Hayes *et al.* 2018), with a number of lines showing ability to persist and produce grain for up to four years, although at a declining plant population (Larkin *et al.* 2014). Investigations by Newell and Hayes (2017) found that as a ‘graze and grain crop’ option, some perennial hybrids yielded more than twice as much vegetative biomass as the annual grazing wheat cultivar and produced no less than 40% of the grain yield of the annual wheat control. In the second year of production, the better performing lines yielded up to 61% more grain than the annual wheat control line. This far exceeded the theoretical benchmarks to be economically feasible previously established in a ‘grain and graze’ model for the crop (Bell *et al.* 2008). Moreover, their model provides a functional example of multifunctionality: the area under crop producing meat, wool and grain within a 12-month period with little additional resources. This increased resource-use efficiency, coupled with beneficial ecosystems services offered via perenniality (Ryan *et al.* 2018) will aid adoption of early-generation perennial crops.

Dual-use perennial grains and polycultures

The initial field evaluation of perennial cereals concluded that early generation perennial wheat was likely to be best adapted to higher rainfall environments in SE Australia, where grazing is the dominant enterprise (Hayes *et al.* 2012). Similar to other grazing cereals, the extra forage produced over autumn and winter increased feed supply when pasture growth rates are low and allows pastures to be rested which leads to improved profitability through increased stocking rates. The greater flexibility from incorporating perennial cereals allows a longer decision-making time frame around grazing and/or grain production compared with annual cropping cycles, enabling producers to be more responsive to climatic conditions and changes in commodity prices (Bell 2013).

The vision for perennial grain agriculture is to move away from the simplified monoculture agroecosystem of modern annual cropping to one that better mimics natural ecosystems, containing a diverse range of complementary species (polyculture). A pilot study was undertaken to investigate the impact on crop yield, total biomass and nitrogen fixation in swards sown to experimental perennial wheat lines grown in mixtures with subterranean clover (*Trifolium subterraneum*) in various spatial configurations (Hayes *et al.* 2017). It was found that separating the perennial crop from the legume in alternate drill rows more than doubled legume biomass compared with where the two species were sown in the same drill row, while having little impact on grain yield. The profitability of perennial cropping systems based on crop-legume mixtures is enhanced by reduced nitrogen (N) fertiliser costs. When estimates of the total inputs of fixed N from the clover were compared with the amounts of N removed in grain by the different perennial wheat treatments, it appears feasible that a companion legume could fix sufficient N to maintain the N balance of a perennial cropping system producing 1.5-2.0 t grain/ha/year.

The inclusion of legumes in a perennial grain polyculture can also have implications for animal nutrition. Similar to some annual cereals, the mineral content of the forage is high in potassium (K) and very low in sodium (Na). Acting together, these mineral levels impair the absorption of calcium (Ca) and magnesium (Mg) in ruminants, leading to increased risk for metabolic disorders in high-producing classes of livestock. Current management therefore recommends mineral supplements of ruminants grazing cereal crops with Ca, Mg and Na. However, this can be inefficient and an additional expense, with some producers still reluctant to graze some classes of livestock on annual cereal crops. The use of legumes in a crop polyculture may provide a solution as they have a different mineral profile compared with cereals and they may be more accessible to all stock compared to mineral supplements. Two studies were undertaken to examine the suitability of perennial wheat combined with a legume to meet the mineral needs of livestock. In the first study, Newell *et al.* (2020b) used 10-month-old lambs to test the effect of perennial wheat forage on growth rates and
carcass characteristics in comparison to annual wheat forage. Individual lambs were fed one of four diets: perennial wheat (PW), annual wheat (W), perennial wheat + lucerne (PW+L) or wheat + lucerne (W+L). The addition of lucerne to the cereal forage significantly increased feed intake ($P < 0.001$) (Figure 1a), but without effects on carcass weight or quality traits. The addition of lucerne improved dietary intake of Na, Mg and Ca, however the concentration of Na and Mg in plasma fell over the course of the experiment (Figure 2) and was accompanied by low urinary excretion of all three minerals (Refshauge et al. in review). The results suggest the addition of lucerne improved Ca status in the lambs but could not resolve the Na deficiency which impaired Mg absorption in the lambs.

In a second study by Newell et al. (2020a), late-gestation twin bearing ewes were fed PW, PW+ Salt (NaCl), PW+L or PW+L+Salt to assess the effect of increased Na on metabolism. Both lucerne and salt when added individually to PW increased feed intake with the combination of lucerne, salt and PW increasing feed intake by 25% compared with PW alone (Figure 1b). Both studies highlight the production advantages of offering a mixed forage for productive livestock, supporting the practice of growing perennial crops in polycultures. However, despite lucerne forage Na concentration being 4-fold greater than perennial wheat, it was still insufficient to resolve the Na deficiency of the mixed forage suggesting that lucerne may not be the best companion species with perennial wheat without providing supplementary minerals for ruminant livestock. Field experiments evaluating the mineral profile and population dynamics of alternative companion legumes, with higher forage concentrations of Na than lucerne, are being evaluated in biculture with PW to assess their ability to meet the mineral needs of grazing ruminants.

**Figure 1.** a) Average daily dry matter intake (kg/day) of lambs fed perennial wheat (PW), perennial wheat + lucerne (PW+L) annual wheat (W) and wheat + lucerne (W+L). b) Average daily dry matter intake of twin-bearing ewes in late pregnancy (kg/day) fed perennial wheat (PW), perennial wheat + salt (PW+Salt) perennial wheat + lucerne (PW+L) and perennial wheat + lucerne + salt (PW+L+Salt). Within each figure, columns with the same superscript not significantly different ($P > 0.05$).
While the majority of research at Cowra has focused on perennial wheat, other perennial grains are also under investigation. Recently imported lines of perennial sorghum (*Sorghum bicolor* x *S. halepense*) are being evaluated for forage and grain production. First year grain yield from the perennial sorghum lines has been low, with the best performing line producing 50% of the grain yield of the grain sorghum check variety Buster (Table 1). Biomass production among the perennial lines was higher than grain sorghum, although lower than the forage sorghum cultivar. The hybrid sorghums display a strong perennial habit and there is some evidence of biological nitrogen fixation (Newell *et al.* 2019). Traditionally, sorghum grain has been used as an animal feed but an increasing number of new human consumption markets are emerging to capitalise on the gluten-free attributes of sorghum. There is potential for perennial sorghum in this market once grain function attributes are understood. The large amount of biomass produced by perennial sorghum also offers opportunities for energy production, another potential example of production efficiency associated with crop multi-functionality. Second year production data continues to be assessed at Cowra.

**Other perennial crop options in Australia**

While the majority of research at Cowra has focused on perennial wheat, other perennial grains are also under investigation. Recently imported lines of perennial sorghum (*Sorghum bicolor* x *S. halepense*) are being evaluated for forage and grain production. First year grain yield from the perennial sorghum lines has been low, with the best performing line producing 50% of the grain yield of the grain sorghum check variety Buster (Table 1). Biomass production among the perennial lines was higher than grain sorghum, although lower than the forage sorghum cultivar. The hybrid sorghums display a strong perennial habit and there is some evidence of biological nitrogen fixation (Newell *et al.* 2019). Traditionally, sorghum grain has been used as an animal feed but an increasing number of new human consumption markets are emerging to capitalise on the gluten-free attributes of sorghum. There is potential for perennial sorghum in this market once grain function attributes are understood. The large amount of biomass produced by perennial sorghum also offers opportunities for energy production, another potential example of production efficiency associated with crop multi-functionality. Second year production data continues to be assessed at Cowra.
Other perennial grains under investigation include the domesticated form of intermediate wheatgrass known as Kernza. Outside of small field experiments, intermediate wheatgrass has not been used in Australian agriculture. The prospects for intermediate wheatgrass remain uncertain as this species has performed better at higher latitudes compared with regions in Australia and Italy (Hayes et al. 2018).

Table 1. Grain weight per plant, thousand kernel weight (TKW) and dry matter per plant (DM/plant) for perennial sorghum lines compared with grain sorghum (*S. bicolor* cv. Buster) and forage sorghum.

<table>
<thead>
<tr>
<th>Entry</th>
<th>812</th>
<th>813</th>
<th>814</th>
<th>815</th>
<th>816</th>
<th>817</th>
<th>818</th>
<th>819</th>
<th>820</th>
<th>821</th>
<th>Buster</th>
<th>Forage sorghum</th>
<th>l.s.d (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain/plant (g)</td>
<td>102.4</td>
<td>12.1</td>
<td>19.3</td>
<td>1.3</td>
<td>26.4</td>
<td>4.0</td>
<td>18.0</td>
<td>5.5</td>
<td>4.2</td>
<td>45</td>
<td>202.0</td>
<td>88.0</td>
<td>59.4</td>
</tr>
<tr>
<td>TKW (g)</td>
<td>16.0</td>
<td>14.2</td>
<td>8.9</td>
<td>9.9</td>
<td>17.1</td>
<td>10.6</td>
<td>11.8</td>
<td>11.2</td>
<td>4.6</td>
<td>34.7</td>
<td>15.0</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>DM/plant (g)</td>
<td>0.228</td>
<td>0.120</td>
<td>0.289</td>
<td>0.194</td>
<td>0.158</td>
<td>0.197</td>
<td>0.154</td>
<td>0.128</td>
<td>0.274</td>
<td>0.169</td>
<td>0.151</td>
<td>0.578</td>
<td>0.105</td>
</tr>
</tbody>
</table>

However, other forage grasses developed in Australia may have potential as a grain crop, such as mountain rye (*Secale montanum*). This forage species was developed in the 1980’s and is suited to sandy acid soils from the Riverina in NSW to montane areas of northern Victoria (Oram 1996). Both Kernza and mountain rye have been evaluated at several sites during 2019 (Table 2). The standout feature was the 1330 kg/ha grain yield of Kernza at the Glen Innes site. Mountain rye produced 50% more biomass across all sites compared with Kernza but did not translate into increased grain yield. This is potentially due to greater selection for grain size in Kernza compared with forage production in mountain rye.

Table 2. Grain yield (kg/ha) and Anthesis dry matter for Kernza and mountain rye across sites in NSW.

<table>
<thead>
<tr>
<th>Site</th>
<th>Kernza Grain yield (kg/ha)</th>
<th>Anthesis dry matter (kg/ha)</th>
<th>Mountain rye Grain yield (kg/ha)</th>
<th>Anthesis dry matter (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooma</td>
<td>0.0</td>
<td>1206</td>
<td>78.9</td>
<td>5645</td>
</tr>
<tr>
<td>Cowra</td>
<td>28.8</td>
<td>6748</td>
<td>13.4</td>
<td>10061</td>
</tr>
<tr>
<td>Glen Innes</td>
<td>1330.0</td>
<td>2820</td>
<td>111.1</td>
<td>5032</td>
</tr>
<tr>
<td>Orange</td>
<td>76.0</td>
<td>925</td>
<td>144.6</td>
<td>2667</td>
</tr>
<tr>
<td>l.s.d (5%)</td>
<td>397.9</td>
<td>2018.7</td>
<td>397.9</td>
<td>2018.7</td>
</tr>
</tbody>
</table>

Conclusion

The future for perennial crops appears promising as current research has demonstrated that multifunctional perennial cereals can contribute significantly to a dual-purpose grain and graze production system. Perennial grains such as sorghum, Kernza and mountain rye continue to be of interest due to their greater persistence compared with wheat derivatives. Selecting for greater seed size to improve grain yields will be important to the development of these species for future use in Australian production systems.
References


Wheat x wheatgrass perennial grains’ introduction to contemporary agroecosystems

Robin Morgan1 and Stephen Jones1,2

1 WSU Breadlab, 11768 Westar Lane. Unit E, Box 5, Burlington, United States (WA), 98233, https://breadlab.wsu.edu/
2 Email: joness@wsu.edu

Abstract

The Washington State University (WSU) perennial grain breeding program was established in 1992. The project developed as a branch of the efforts that focused on the introgression of useful traits from wheatgrass (Thinopyrum spp.) to domestic wheat (Triticum aestivum). We have defined the perennial habit observed in Triticum aestivum x Thinopyrum spp. hybrids, as post-sexual cycle regrowth (PSCR) specifically referring to the uninterrupted biomass production initiated by axillary meristems, located in the plant’s crown. The senescence mechanism, characteristically triggered for annual grasses during the later stages of seed development, is disrupted, allowing the plant to continuously develop new fertile tillers, whose reproductive success is limited only by environmental conditions. The genetic control of the PSCR, has been attributed to the addition of a single Thinopyrum elongatum chromosome (4E) to the domestic wheat genome, minimizing the sacrifice of wheat derived traits.

Currently, partial and complete amphiploids are under evaluation in western Washington State (USA) for traits like PSCR, second-year spring regrowth and fertility. The best hybrids, selected in the 2020 growing season, will be intercrossed with each other, with the intention of assessing genetic dosage as an element contributing to the expression of the perennial growth habit and the development of genotypes with improved agronomic traits. This strategy contributes to the further establishment of a new polyploid species (x Tritipyrum aaseae Curwen-McAdams et al. 2017).

From an end-use perspective, the lines currently under evaluation have successfully been employed in malting/brewing and in baking. Salish blue, one of the elite hybrids, has recently been malted and brewed into a saison beer and flour for baking is being sold commercially.

Key words: Cropping system, ecosystem services, iteroparity, dormancy, harvest index, externalities

Introduction

Domestic wheat (Triticum aestivum L.) does not present genetic variation for perennial or annual growth habit. Centuries of human and natural selection and spontaneous polyploidisation events, gradually determined the emancipation of annual, monocarpic species from endemic, perennial, polycarpic grasses. Despite the chronological and evolutionary distance that built up since then, domestic wheat still presents enough genetic similarities to allow for the development of fertile hybrid progenies with polycarpic wild relatives. This latent relatedness has been exploited by breeders following two fundamentally distinct frameworks. The first, focuses on promoting the transfer of genes from one of the three monocarpic diploid species (Aegilops tauschii, Triticum urartu, Aegilops speltoides) that, through successive hybridisation events, constituted domestic wheat as an
allopolyploid. The second, focuses on less related species, among which polycarpic wheatgrass (*Thinopyrum spp.*), to import alien genes into the domesticated wheat background (Jones *et al.* 1995). Following the second strategy to find genetic resistance to cephalosporium stripe (*Cephalosporium gramineum*), the Washington State University (WSU) winter wheat breeding program incurred into hybrids that presented a second phase of tiller initiation named post-sexual cycle re-growth (PSCR) (Lammer 2004). By studying the phenotype of Chinese spring wheat x wheatgrass disomic addition lines (2n= 42+2), the genetic control of PSCR has been narrowed to loci found on *Thinopyrum elongatum*’s (2n=2x=14) chromosome 4E (CS+4E). The plants retain the capability of supporting tillers at different physiological stages, rather than enacting a whole-organism senescence, as typically seen in domestic wheat.

This paper discusses aspects of perennial grains integration in contemporary cropping systems, with an emphasis on their capacity for shifting agricultural planning towards a more nuanced and less binary direction. In addition, the topics of selective senescence, winter dormancy and end-use of wheat x wheatgrass hybrids will be addressed to better clarify the current factors hampering the establishment of perennial grain species.

**Perennial grain species’ integration**

The development of a perennial grain crop based on wheat, has been pursued for almost a century (Tzitzin 1933). For the most part, perennial grains have been a long-term project of researchers interested in offering a major way of diversifying cropping systems. Despite the appropriateness of their vision, the results of their efforts had still to face the mentality of their times. The focus on productivity, derived from a post-world war two cultural context, may well have pressured plant breeders to not squander their attention on the development of a grain crop that would not need to be sown every year, focusing instead on what was currently, and what would eventually, be feeding billions of people—annual species. The technological advancement of agriculture followed a similar path across cultures and continents. The main lines of thought of such a transition are the substitution of human labour with more and more effective machines, the provision of a steady and abundant supply of plant nutrients and the development of plant varieties complementary to the first two lines of improvement. Among others, Tzitzin in Russia and Suneson in the United States (Suneson *et al.* 1963), took the chance of assessing the benefits that could come from introgressing wild relatives’ genes into wheat backgrounds and for the first-time observed plants that resembled wheat but presented physiological differences, among which, an altered senescence pattern reminiscent of a perennial growth habit. Great must have been the excitement for what could have been reasonably seen as another, almost miraculous, achievement of the recently celebrated marriage of humankind and science. These events unfortunately did not overcome the incumbent short-term pressures of feeding a growing human population, and of the vast reliability of annual semelparous species in doing so.

Many decades after those efforts, perennial grains have risen to the awareness of an increasingly broader audience (Haspel 2019). What used to be an idea shared only among interested researchers, has become a symbol for a group spanning from eaters to plant breeders to rally and support the creation of a new covenant with planetary resources. Above all soil. The main critique of the development of iteroparous grain species is focused on the yield gap that they present when compared to their semelparous counterparts, namely domestic wheat. This gap presents itself both from a theoretical and practical perspective but instead of using it to prove the unfitness of perennial grains for contemporary farming systems, is there to remind us that the era of linear, excessively reductionist solutions is over. Domestic wheat has been bred to embody the essence of an annual semelparous species. A plant that has been studied and selected to develop only the essential structures needed for supporting its reproductive efforts, a trait known as high harvest index, and to effectively reallocate internal resources towards grain filling— to produce higher yields. Everything is sacrificed for the caryopses, while what once was a plant becomes only a blonde, standing support. Domestic wheat x
wheatgrass hybrids are found on a different part of the harvest index spectrum. Their capability of presenting a second phase of initiation and development of reproductive tillers, clearly sets them apart from single stem dwarf wheat varieties and exposes them to doubts and concerns centred on resource use inefficiencies, eventually leading to grain yield loss through the excessive production of biomass not for human consumption. At the same time, the introgression of alien chromatin, in the form of chromosomes or genes, from non-domesticated species has the potential of disrupting the wheat genome through the inclusion of undesirable traits (head threshability and shattering) genetically linked to the sought after post-sexual cycle regrowth or by compromising the fertility of hybrids’ florets. The efforts of plant breeders invested in this type of research lay in the overcoming of these aforementioned heritable issues and not in the process of making new amphiploid species conform to a problematic conception of agricultural productivity.

Iteroparous perennial grains are leading the implementation of practices aimed at the restoration or maintenance of soil health directly into food producing endeavours. Persistent soil cover and improved nutrient retention, together with soil erosion reduction are the prominent ecosystem advantages offered by emerging practices like cover cropping. However, despite its importance, the cover crop approach is still confined within the boundaries of an alternation between extremes. In such a system the farming pendulum swings from a crop that often requires high investments in terms of soil resources but yields a profitable return in the form of a harvest (for example domestic wheat or corn) and that of a cover crop, yielding the above-mentioned ecosystem services but sacrificing equally essential financial rewards. Perennial grains offer a new intersection of those scenarios and because of this, their development should not be weighed down by the inaccurate comparison with annual wheat and the often related, grain centred conception of yield. Perennial grains provide an agronomic step stone towards the adoption of a diversified notion of yield. Domestic wheat x wheatgrass hybrids’ growth patterns could in fact offer a financially and agronomically sound path, to facilitate the re-integration of animal husbandry with row-crops operations (Bell et al. 2008; Newell and Hayes 2017). In this way, turning what could be deemed an inefficient plant, because potentially diverting resources from grain filling to stem development, into an effective way to realise a more complementary agroecosystem. An approach aimed at minimizing the negative externalities of agricultural production (for example soil erosion and ground water pollution) without renouncing to a core purpose of farming itself, which is the production of primary resources for human societies.

Selective senescence and winter dormancy

WSU Breadlab is in Western Washington State, a coastal region with a temperate, warm, dry summer climate (csb) according to the Köppen-Geiger classification (Kottek et al. 2006). The major environmental obstacle to breeding lines capable of PSCR is represented by overcoming the winter following the first grain harvest. An incomplete enactment of dormancy related strategies leaves the plants in a phenologically inappropriate state for environmental conditions characterised by near freezing temperatures (average temperature of 5 C from December to April) and lack of snow cover for only a few days in the January-February period. Lines producing new reproductive stems that attempt to reach cycle completion beyond the standard, domestic wheat timeframe could be grouped into two categories (figure 1,2,3). The first includes those genotypes that do not overwinter, probably because of the lack of photosynthate accumulation and the persistence of a reproductive centred approach. This continues despite the diminishing returns of the photosynthetic process caused by the dramatic changes in day-length and air temperature. The second group consists of plants that, during the seasonal transition from winter to spring, enact the development of a novel set of reproductive tillers. Shoots that develop out of meristems located at the first basal node of the previous growing season’s stems indicate the presence of a dormant stage. In these shoots the under/above ground physiological functionality is retained throughout winter, a trait arguably derived from the iteroparous parent.
A functional implementation of dormancy is essential for turning a plant with continuous production of biomass, PSCR, into a perennial, polycarpic grain species. Wheatgrass, as other iteroparous grasses, evolved the competence of enacting an appropriate form of resource partitioning, combining seed set and the persistence of crown buds. This is an effective strategy disrupted by the otherwise, kernel focused, nutrient translocation endeavours proper of a semelparous, annual species as domestic wheat (Hughes 2017). Current inter-generic hybrids cover the intermediate region defined by the above-mentioned extremes, expressing an iteroparous habit whose penetrance is affected by environmental conditions including crop management. It has been reported that post-harvest practices can affect the rate of second-year regrowth (Clark et al. 2019), with post-grain harvest cutting of stubble and PSCR shoots increasing the second-year regrowth rate of domestic wheat x wheatgrass hybrids. This phenomenon may be determined by a forced interruption of the plant’s reproductive efforts, a disruption that, paired with the environmental signalling proper of the onsetting fall, could prevent the plant from reiterating the development of reproductive tillers in favour of a secondary vegetative strategy more resembling of a winter dormancy.

From an agronomic perspective, wheatgrass presents a caespitose overwintering habit that if successfully transferred to wheat x wheatgrass hybrids, would facilitate weed management of the post-harvest phase, reducing the need for chemical or physical interventions, while also representing a valuable source of forage. The improvement of the overwintering habit and re-growth vigour are the essential aspects driving the current efforts in breeding a perennial grain crop

**End-use**

End-use is one of the areas in which the distance between a domesticated and a wild species is the greatest. In the case of domesticated wheat, every utilisation of the grain has imparted its influence on breeding endeavours, of which seed size is the most evident. The introgression of entire genomes, from the iteroparous parent inevitably affects the technological qualities of grains, yielding caryopses closer to their ancestral and essential function of being a seed and further from that of being food. Similarly to what can be foreseen for the agronomic context, the end-use of perennial grains will likely have them adopted in products with the co-occurrence of annual grains, whose technological
traits have been already established, at this point, for decades, if not centuries. Domestic wheat x wheatgrass hybrids present valuable nutritional qualities expressed in the form of higher mineral and protein concentration (Murphy et al. 2009) when compared to annual wheat references. This is due in part to the contribution of the wheatgrass parent in the form of seed shape and size, determining a ratio of endosperm to pericarp in favour of the latter. Currently, such experimental lines would not fit into conventional grain commodity categories and hence their successful use is more appropriate for food producers whose processes have a broader range of adaptability. Salish blue, a domestic wheat x wheatgrass hybrid, provides an example of this. Its wheat like kernels, have been successfully malted and brewed into a saison beer. A result also made possible by maltsters and brewers willing to adapt their processes to the pursuit of uniqueness. Moreover, by doing so remarking the critical role that grain users have in supporting the development and betterment of unconventional plant breeding projects, by facilitating the access to market and overall a broader range of people.

The improvement of end-use quality is a priority of second order, having to yield to agronomic performance first. The continuous development of hybrid germplasm, broadening the genetic base on which to apply selection, is the foremost concern now and, similar to what has happened to other grain crops, will allow for the establishment of breeding lines showcasing particular traits, including end-use quality.

Conclusions

Perennial grain crops represent an example of how plant breeding can shape food landscapes. The historical inconsistencies of the efforts in such direction have hampered the success and establishment of new species that would facilitate a productive acknowledgment of some of the negative externalities of contemporary agriculture.

In a time affected more than ever by looming and ongoing global crises, perennial grains have captured the non-specialized awareness, gaining a broader base of support. The task is far from finished. A platform for continuous collaboration is deeply needed to fill the knowledge and practical gaps still preventing perennial grains from transitioning from botanical oddity to sound agronomic option.

References


Agronomic, technological and nutritional characterisation of selected perennial wheat lines grown in Italy

Laura Gazza1,2, Elena Galassi1 and Pierino Cacciatori1

1 CREA – Research Centre for Engineering and Agro-food Processing (CREA-IT), Via Manziana 30, 00189 Rome, Italy
2 Email: laura.gazza@crea.gov.it

Abstract

As part of the international network led by The Land Institute (USA) and the NSW Department of Primary Industries (Australia), twenty genotypes of perennial wheat obtained from crosses between *Triticum aestivum* or *T. durum* and *Thinopyrum* spp. were grown during ten years of testing at Montelibretti (Rome). Germplasm was tested both in 1.0 m rows arranged in a randomized block design with three replicates, or in replicated, randomized larger plots (10 m²) and compared for their agronomic, technological and nutritional traits with different cultivars of annual wheat commonly grown in Italy. All the experimental entries demonstrated some capacity of post-harvest regrowth (PHR) and produced grain in two or three successive years. The experimental genotypes were highly polymorphic, produced soft or medium-hard kernels and showed lateness of ear emergence, small kernel size, low density ears, high number of tillers and high level of disease resistance against rusts, septoria complex and powdery mildew. Compared with annual cultivars, the perennial germplasm exhibited a low percentage of hull-less kernels, high protein content, reduced SDS-sedimentation volume, low gluten index, high content of bioactive compounds such as fibre, 5-n-alkylresorcinols and soluble polyphenols, and increased amounts of yellow pigments and resistant-starch. The poor gluten quality of the perennial lines appeared to be associated with a high ratio of gliadins, and with the presence of unusual HMW glutenin subunits inherited from *Thinopyrum*. Amongst the perennial lines, four genotypes (235a, 11955, OK72 and 280b) were identified and selected for their higher nutritional and technological quality and are the object of an EU funded project (CHANGE-UP, PRIMA program) which aims to assess the agronomic and environmental adaptation of selected perennial wheat to Mediterranean environments of Italy, Tunisia, Algeria and Morocco. These four genotypes will be evaluated for their agronomic and technological performance and the impact on soil/water resources compared to annual wheat counterparts.

Key words: Perennial wheat, *Thinopyrum* spp., wheatgrass, nutritional quality, sustainability

Introduction

Cereals are the base for human nutrition. Amongst cereals, wheat is the most widely grown with 61 M ha in Europe, 7.1 M ha in Northern Africa and about 8 M ha in Eastern Mediterranean countries (FAOSTAT 2018). In these areas, wheat plays a very important role in food security. Development of perennial wheat appears to be a novel strategy towards the implementation of sustainable agricultural production, food security and environmental quality (Glover et al. 2010). In the present study, twenty perennial wheat derivatives obtained by crossing wheat (*Triticum aestivum*) and durum wheat (*T. durum*) with various perennial wheatgrasses, *Thinopyrum elongatum*, *Th. intermedium*, *Th. junceum*...
or *Th. ponticum* and developed by Washington State University (WSU) and The Land Institute (TLI), were grown in replicated rows in Central Italy and compared with commercial annual common wheats for their agronomic, biochemical, nutritional and technological traits. Amongst them, four genotypes were identified for their higher nutritional and technological quality (Gazza *et al.* 2016) and are the object of the CHANGE-UP project financed by EU (2021-2024), whose primary aim is to re-design innovative farming systems for the Mediterranean area (Italy, Algeria, Tunisia, Morocco) more resilient to climate change and able to face and overcome adverse and unpredictable events while ensuring food security and sustainable farm incomes.

**Methods**

Perennial wheat breeding lines (Table 1), provided through an international network of field trials (Hayes *et al.* 2018), were sown at the experimental field station of CREA-IT at Montelibretti (Rome). Experiments included 1.0 m rows with 30 seeds (0.5 m between single rows) arranged in a randomized block design with three replicates, or in randomized larger plots (10 m² eight rows, 17 cm apart, 400 germinating kernels/m²) with three replicates. Two annual wheat cultivars commonly grown in Italy cvs ‘Enesco’ and ‘Bologna’, were used as controls.

**Table 1. Genotype and pedigree of perennial wheat lines tested over 10 years at Montelibretti (Rome)**

<table>
<thead>
<tr>
<th>Genotype acronym</th>
<th>Genotype name</th>
<th>Pedigree</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>11955</td>
<td>11955</td>
<td><em>T. aestivum / Th. ponticum</em></td>
<td>USA</td>
</tr>
<tr>
<td>20238</td>
<td>20238</td>
<td><em>T. turgidum / Th. elongatum</em></td>
<td>CIMMYT</td>
</tr>
<tr>
<td>235a</td>
<td>CPI147235a</td>
<td><em>Th. elongatum / T. aestivum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>236a</td>
<td>CPI1472365a</td>
<td><em>Th. elongatum / T. aestivum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>244b</td>
<td>CPI147244b</td>
<td><em>Th. elongatum / T. aestivum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>251b</td>
<td>CPI147251b</td>
<td><em>Th. elongatum / T. aestivum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>280b</td>
<td>CPI147280b</td>
<td><em>Th. intermedium / T. carthlicum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>281b</td>
<td>CPI147281b</td>
<td><em>Th. intermedium / T. carthlicum / T. aestivum</em></td>
<td>WSU, USA</td>
</tr>
<tr>
<td>954</td>
<td>CPI-149793- B913(3)-6-1</td>
<td><em>T. durum x Th. junceum</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>967</td>
<td>CPI-149808- B1107(2)-14</td>
<td><em>T. durum x Th. junceum</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>968</td>
<td>CPI-149809- B1107(4)-13</td>
<td><em>T. durum x Th. junceum</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>969</td>
<td>CPI-149810- B1107(4)-8</td>
<td><em>T. durum x Th. junceum</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>Agrotana</td>
<td>Agrotana</td>
<td><em>T. aestivum / Th. ponticum</em></td>
<td>Unknown</td>
</tr>
<tr>
<td>B373</td>
<td>B373</td>
<td><em>T. aestivum / Th. intermedium</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>B913</td>
<td>B913</td>
<td><em>T. aestivum / Th. junceiforme</em></td>
<td>TLI, USA</td>
</tr>
<tr>
<td>OK72</td>
<td>OK7211542</td>
<td><em>T. aestivum x Th. ponticum</em></td>
<td>USA</td>
</tr>
<tr>
<td>Ot38</td>
<td>Otrastauscja 38</td>
<td><em>T. aestivum x Th. intermedium</em></td>
<td>Russia</td>
</tr>
<tr>
<td>PWM706/PWM3</td>
<td>PWM706/PWM3</td>
<td><em>T. aestivum x Th. ponticum</em></td>
<td>Russia</td>
</tr>
<tr>
<td>TAF46</td>
<td>TAF46</td>
<td><em>T. aestivum x Th. intermedium</em></td>
<td>France</td>
</tr>
<tr>
<td>Zhong7</td>
<td>Zhong 7</td>
<td><em>T. aestivum x Th. intermedium</em></td>
<td>China</td>
</tr>
<tr>
<td>Bologna</td>
<td>Bologna</td>
<td><em>T. aestivum</em></td>
<td>Italy</td>
</tr>
<tr>
<td>Enesco</td>
<td>Enesco</td>
<td><em>T. aestivum</em></td>
<td>Italy</td>
</tr>
</tbody>
</table>
At maturity, length of the main stem and total number of tillers of three plants per genotype were recorded. After harvest, in late July, plants were cut at approximately 10 cm from the soil surface and spikes were threshed to determine percentage of hull-less kernels, number of spikelets and kernels/spike, 1000-kernel weight and test weight. Each genotype received a Post-Harvest Regrowth (PHR) score based on the average percentage of the original plant population that was re-growing in the three replicates during the three months after harvest. Analyses were performed on wholemeal flour from mature kernels of each replicate, ground with a laboratory mill. The 5-n-alkylresorcinol content, free polyphenol content (Ciccoritti et al. 2013), total yellow pigment (AOAC 1975) expressed as ppm of β-carotene, total starch (AOAC 1996), total dietary fibre (AOAC 1995), resistant starch (McCleary et al. 2002) and protein content (micro-Kjeldahl, N x 5.7). Gluten quality was evaluated by the SDS (sodium dodecyl sulfate) sedimentation test using a solution of 2% sodium dodecyl sulfate as described by the standard method 56-70 (AOAC 1995), and the sedimentation volumes were expressed in milliliters (mL). Kernel hardness was evaluated on 100 hull-less kernels by the Perten SKCS 4100 (Springfield, IL, USA) following the manufacturer’s operating procedure. Puroindolines were extracted as described by Corona et al. (2001). Gliadins and total proteins were extracted and fractionated by A-PAGE and SDS-PAGE, respectively, as described by Pogna et al. (1990). Western blotting was performed using a polyclonal antiseraum developed in rabbits challenged with the 10-mer synthetic QQPQDAVQPF peptide (Gazza et al. 2006).

Results reported refer to average observations over 10 years of different field trials at CREA-IT (Rome).

Results and discussion

Post-harvest regrowth

Wheatgrasses Th. intermedium and Th. ponticum revealed Post Harvest Regrowth scores as high as 66.7% and 80%, respectively. The PHR percentages of the perennial wheat derivatives were significantly lower than their perennial counterparts and varied between 5.6% (line 244b) and 42.1% (line OK72) without any evident association between PHR score and genetic origin. In this context it is noteworthy that the PHR values of lines 235a, 280b, 11955 and OK72 were comparable with those of the best genotypes analysed over three consecutive years of cultivation in Australia by Hayes et al. (2012). The wide variation observed between the PHR scores of the different genotypes is in accordance with the polygenic control of this trait and with a possible interaction between critical genes inherited from both perennial and annual parents.

Morphological and physiological traits

The perennial wheat derivatives proved to be significantly different for all the morpho-physiological traits analysed in comparison to the annual cvs Bologna and Enesco. Perennial lines on average were taller than their annual wheat counterparts (88 vs 70 cm), the maximum value in line 20238 (152 cm) and the minimum in line 969 (30 cm). Plant height, with a huge variability in the perennial derivatives, was clearly modulated by genes inherited from the wheatgrass parents, which showed highest values in Th. intermedium and Th. ponticum (130 cm and 167 cm, respectively). On average, the perennial lines, compared to annual varieties, were characterized by lateness of ear emergence (20-50 days later), higher number of tillers (11.5 vs 6.1), longer ears (12 cm vs 9.5 cm), loose spikes (1.4 vs 2.2 spikelets/cm), reduced number of kernels per spike (31 vs 69) and smaller kernels (29 vs 40 mg). In addition, the perennial wheat derivatives revealed mean test weights lower than those of annual controls (68 vs 75 kg/hL). It was evident that perennial species allocate, especially in the first year of growth, a significant proportion of photosynthetates to roots and green tissues, whereas annual species use a greater part of their photosynthetic energy for seed development. All perennial wheat genotypes produced seeds with tenacious glumes and upon a single passage through a micro-thresher their spikes released a low percentage of hull-less kernels (20.7 to 63.0 %) compared with control cultivars (84.9 and 91.8%).
Leaves and stems of perennial wheat derivatives showed no damage due to powdery mildew and rusts (*Puccinia* spp.), with the exception of lines 251b and 236a, which revealed slight symptoms of stem rust (*Puccinia graminis tritici*). By contrast, line 244b was heavily attacked by *Helminthosporium* spp. On the contrary, annual controls showed moderate-heavy attacks from yellow, leaf and stem rusts and Septoria complex.

**Quality traits**

Protein contents as high as 19.7 to 23.7% were observed in the perennial wheat derivatives, with an average value of 20.7%, 5 percentage units higher than those of their annual counterparts (15.5%). On average, the perennial wheat derivatives revealed a poor gluten quality as determined by the SDS test, line 235a being unique in showing an SDS sedimentation volume as high as 58 mL. Italian common wheat cultivars with a good gluten quality show sedimentation volume higher than 50 mL. On average, all the lines tested revealed low gluten index (45). The low gluten quality of these lines was likely due to their HMW glutenin subunits (HMW-GS), which are known to play an important role in the viscoelastic properties of dough.

In particular, upon SDS-PAGE fractionation, six perennial lines (11955, OK72, Ot38, 235a, 280b and 281b) showed no trace of HMW-GS inherited from the wheatgrass parent and exhibited the commonly occurring subunits 1 or 2* encoded by the *Glu-A1* locus on the long arm of wheat chromosome 1A together with subunits 20, 7*+ 8 or 7+9 encoded by the *Glu-B1* locus (chromosome 1BL) and subunit pairs 2+12 or 5+10 encoded by the *Glu-D1* locus (chromosome 1DL). By contrast, lines 236a, 244b and 251b exhibited unusual HMW-GS likely inherited from the wheatgrass parent and lacked HMW-GS encoded by the *Glu-D1* locus on chromosome 1DL. In addition, line 244b did not show any subunit encoded by the *Glu-B1* locus. SDS-PAGE fractionation of 10 single kernels from each genotype revealed that the wheat x wheatgrass derivatives were homogeneous for their HMW-GS composition, with the only exception of line 281b, which turned out to be a mixture of three different genotypes (biotypes) with contrasting HMW-GS compositions at *Glu-A1* (subunit 1 or Null) and *Glu-D1* (subunit pair 2+12 or 5+10).

Gliadin patterns of the perennial wheat derivatives fractionated by A-PAGE were comparable with those of annual wheat cv Chinese Spring. However, lines, 236a, 244b, 251b and Ot38 revealed some ω- or γ- gliadins inherited from the wheatgrass parent. Upon A-PAGE fractionation of gliadins from single seeds, line 236a, 235a and 281b turned out to be a mixture of two or more biotypes with contrasting gliadin bands encoded by homeologous group 1 chromosomes of common wheat.

Kernel texture is a main determinant in end product quality because of its strong effects on milling conditions, granularity of flour and starch granule integrity. Kernel hardness was determined by the SKCS method using 50 grains for each genotype; it was found to be typical of soft-textured (mean SKCS index=30) or medium-hard common wheat (mean SKCS =68). In common wheat, grain texture is controlled by the *Ha* locus on the short arm of chromosome 5D. This locus is inseparably linked to the *Pina-D1* and *Pinb-D1* genes coding for puroindoline a (PIN-A) and puroindoline b (PIN-B), respectively. Upon A-PAGE fractionation, the perennial wheat derivatives exhibited puroindoline-A (PIN-A) and puroindoline-B (PIN-B) inherited from either wheatgrass or common wheat. Novel, slow-moving PIN-A and PIN-B likely inherited from wheatgrass (*Thinopyrum* spp.) occurred in the medium-hard kernels produced by lines 235a, 280b and 281b. By contrast soft-textured perennial lines 236a, 244b, 251b, 11955, OK72 and Ot38 exhibited wild-type PIN-A and PIN-B. When submitted to PCR amplification and sequencing, these latter lines revealed the softening alleles *Pina-D1a* (coding for PIN-A) and *Pib-D1a* (PIN-B) inherited from common wheat, whereas lines 235a, 280b and 281b showed three unusual alleles, likely inherited from wheatgrass parent.

**Nutritional traits**

It is well-known that wholegrain cereals are a rich source of unique bioactive compounds that significantly help to promote human health. The bioactives analysed in this study were polyphenols (TSPC), dietary fibres, resistant starch, yellow pigments and alkylresorcinols (ARs). On average, the...
total content in bioactive compounds 5-n-alkylresorcinols (366 µg/g), soluble total polyphenols (319 mg/g) and dietary fibre (15.1%) was higher in perennial wheat lines compared with annual wheats (308 µg/g, 280 mg/g, 13.4% respectively). However, there was a considerable variability for these bioactive compounds among the germplasm in this study. As expected, the high protein content of perennial lines was associated with a reduced amount of total starch content in comparison to the annual wheat controls (55.3% vs 73.7%). Furthermore, on average, perennial lines exhibited higher total yellow pigment content (7.3 ppm vs 5.1 ppm) and resistant starch content (0.60% vs 0.38%), in comparison with annual wheat counterparts. Interestingly, all perennial wheat lines exhibited a high concentration of RS, which resulted in a high RS/TS ratio (1.0 vs 0.5).

Wheat intolerances

In recent years, there has been a substantial increase in the prevalence of gluten intolerance including allergy, celiac disease (CD) and gluten sensitivity (non-celiac gluten intolerance). This prompted changes in the dietary behaviour of a large proportion of European, American and Australian people with increased demand for gluten-free products. Ingestion of gliadin and glutenin peptides is the critical etiological factor in CD, and a strictly gluten-free diet is the only effective therapy. The gluten protein contains more than 20 distinct gliadin or glutenin subunit peptides that are able to elicit proliferation of T-cells in the small intestine of the CD individuals. More interestingly, minor variation of amino acid sequences of some of those immunogenic epitopes were found to prevent activation of T-cells by toxic gliadins, suggesting a new treatment of CD based on these modified peptides. Amongst the “protective peptides”, the 10-mer QQPQDAVQPF sequence was found to prevent proliferation of intestinal lymphocytes and lesions of intestinal mucosa exposed to gluten proteins (Silano et al. 2007). In the present study, the antiserum developed against this peptide was used to screen the perennial wheat derivatives and their wheatgrass parents by western blotting of gliadins and total storage proteins. All the Th. junceum seeds fractionated by SDS-PAGE were found to contain prolamins, about 45 kDa in size, which were recognized by the QQPQDAVQPF antiserum.

Conclusions

Besides the perennial habit, Th. elongatum, Th. intermedium and Th. ponticum were found to contribute a superior phytochemical profile to their wheat progeny by increasing the amount of bioactive and health-promoting compounds such as carotenoids, soluble polyphenols and alkylresorcinols. In addition, Th. junceum attracts certain attention as a potential donor of the “protective peptide” QQPQDAVQPF. On the other hand, the mediocre breadmaking performances of the perennial wheat derivatives analysed here was partly due to the presence of poor-quality HMW glutenin subunits inherited from their wheat parents. Backcrosses of these perennial genotypes with common wheat cultivars of superior breadmaking properties and selection for the presence of good-quality HMW and LMW glutenin subunits in the resulting perennial progeny is expected to improve their end-use quality.

Compared with annual common wheat, the perennial wheat lines analysed exhibited poor agronomic performance coupled with high protein contents and increased amounts of compounds with antioxidant properties such as yellow pigments and 5-n-alkylresorcinols (ARs). The behaviour of the perennial wheats during consecutive years of growing is currently being investigated, focusing on the role of late heading on their agronomic and nutritional performances. Crosses of the present perennial wheat derivatives with Italian wheat genotypes are expected to originate superior progeny with improved agronomic traits and increased grain yield in the Italian environment but we met several concerns about fertility of the crosses.

The successful development of perennial wheat cultivars and their widespread adoption by millers, bakers and consumers will be facilitated by improvement of kernel threshability, milling and bread making quality, and nutritional characteristics including gluten digestibility. Therefore, in addition to addressing the major agronomic traits (grain yield, PHR and disease resistance), good milling and
baking quality and superior nutritional quality seem to be key traits to target for genetic improvement. The wide variation in storage protein composition and bioactive compounds detected in the germplasm analysed here can be easily exploited by breeders in the development of new perennial wheat genotypes with improved end-use qualities.

References


Hedonic exploration of sensory attributes from sourdough loaves made from perennial wheat

Matthew T. Newell1,7, Sarah Baker2, Katrina Sinclair3,4, Richard C. Hayes5 and Emily Salkeld6

1 NSW Department of Primary Industries, Agricultural Research and Advisory Station, Cowra, NSW 2794
2 Tamworth Agricultural Institute, NSW Department of Primary Industries, Tamworth, NSW 2340
3 Wollongbar Primary Industries Institute, NSW Department of Primary Industries, Wollongbar, NSW 2477
4 Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW 2650
5 Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW 2650
6 Small World Bakery, Langhorne Creek, SA 5255
7 Email: matt.newell@dpi.nsw.gov.au

Abstract

Perennial wheat is a new crop for Australia and understanding consumer preference will be important in developing this material for human consumption. Little is known about the sensory attributes of hybrid perennial wheat material when used in the production of sourdough bread. In this preliminary study, data for consumer liking was collected from different sourdough loaves made from two perennial wheat breeding lines, a commercial annual wheat cultivar, and a population wheat. A simple hedonic scale was used by a sensory panel (n = 20) to rate each bread loaf for appearance, aroma, texture and flavour in a blind tasting assessment. Participants were also asked which loaf they would most likely purchase. Sourdough bread made from the population wheat rated significantly higher (P < 0.05) for appearance than the other loaf entries. There were no significant differences found between the four types of sourdough bread in terms of consumer scores for aroma, texture or flavour. There was an overall greater liking for the population wheat loaf with 45% of participants indicating they would purchase this bread compared to the other entries. The sensory performance of the perennial wheat lines was equal to that of the commercial annual wheat cultivar. Further development of perennial wheat should consider sensory attributes as well as agronomic performance when selecting for traits to improve the material to meet end user requirements.

Key words: Taste preferences, organoleptic characteristics, sensory scaling

Introduction

In Australia, perennial wheats derived through hybridisation between bread wheat (Triticum aestivum) and perennial wheatgrass species (Thinopyrum sp.) are being evaluated as dual-purpose crops: producing forage and harvestable grain (Newell et al. 2020). Currently, many of the hybrid grains are unable to meet minimum Australian classification standards for milling wheats, relegating the grain to entry level stock feed grades (Hayes et al. 2012). Small grain size and altered behaviour of high and low molecular weight proteins and the polymers built from them, are key attributes where perennial wheats deviate from standard commercial wheat cultivars. This is likely due to chromosome additions from the perennial parent as most of these traits are under genetic control. Breeding perennial wheat material with the desirable quality characteristics to produce products for human consumption would enhance its viability as an alternative crop in mixed farming systems, due to the higher value of grain (Sinclair et al. 2021).
There is an increasing interest in wheat sourdough bread, in Australia, as consumers seek a wider range of foods with improved nutrition and flavour (IBISWorld 2019). Artisan bakers, the world over, are responding to this consumer demand by turning to historic wheat cultivars with different flavour profiles that are not found in modern wheat cultivars as a result of their selection for high white flour yield (Jones and Econopouly 2018). Perennial wheats have been shown to have higher mineral contents, attributes associated with improved human health (Murphy et al. 2009; Pogna et al. 2014) and may have an altered flavour profile influenced by its genetic background. A recent pilot study using perennial wheat demonstrated good utility across a range of sourdough products, despite the concern of altered end use function compared to conventional wheat (M. Newell unpublished data).

As an emerging crop in Australia, understanding consumer preferences and the acceptability of products derived from perennial wheat will be important in further developing this material for food markets. Sensory studies are typically used to test food and drink preferences and acceptability, with a 9-point hedonic scale the most commonly used (Lim 2011). This small sensory study was a first attempt to capture liking data of sourdough loaves made from two perennial wheat breeding lines, a population wheat developed from a mix of historic cultivars and a commercial bread wheat.

Materials and methods

Grain entries and milling

All grain used in this study was year 1 grain produced during the 2020 growing season. Perennial wheat derivatives Ot-38 and Summer 1 were grown at the Wagga Wagga Agricultural Institute, while the commercial wheat cultivar, Wedgetail was produced at the Cowra Agricultural Research Station. The population wheat was developed at Small World Bakery, Langhorne Creek, South Australia over the last three years. The population contains heritage varieties Calaby’s Glory, Rattling Jack, Yandilla, Marshalls Prolific and Banks. These were added to a separate population of pre-1950 wheat cultivars from Western Australia and grown together for the first time in 2020 (Table 1).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Country of origin</th>
<th>Cultivar</th>
<th>Pedigree</th>
<th>Growing location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Russia</td>
<td>Ot-38</td>
<td><em>Triticum. aestivum</em> x <em>Thinopyrum intermedium</em></td>
<td>Wagga Wagga, NSW</td>
</tr>
<tr>
<td>B</td>
<td>Australia</td>
<td>Wedgetail</td>
<td><em>T. aestivum</em></td>
<td>Cowra, NSW</td>
</tr>
<tr>
<td>C</td>
<td>Australia</td>
<td>Population wheat</td>
<td><em>T. aestivum</em> mix pre-1950 Australian cultivars</td>
<td>Langhorne Creek, SA</td>
</tr>
<tr>
<td>D</td>
<td>China</td>
<td>Summer 1</td>
<td><em>T. aestivum</em> x <em>Th. intermedium</em></td>
<td>Wagga Wagga, NSW</td>
</tr>
</tbody>
</table>

The milling and bread making was undertaken by an experienced baker at the Small World Bakery. The four grain samples were milled separately using a New American Stone Mill (Elmore Mountain Bread, Vermont) and coarse sieved to remove large bran and glume material to produce a 96% extracted whole wheat flour. There was a limitation of grain supply for the two perennial wheat derivatives and the conventional wheat compared to the population wheat. This reduced the total dough volume available for these entries during the bread making process.
**Bread making process**

The baking was conducted using a naturally leavened style in which 8% of the flour was pre-fermented in a stiff sourdough culture overnight. A pre-gelatinised paste, comprising flour (5% of total ingredients), water (25% of total ingredients) and salt (1% of total ingredients), was cooked at 80°C and cooled. The remaining flour and water were then mixed with the starter and gel components to produce a dough and fermented for 2-3 hrs at room temperature. The dough was pre-shaped into 780g lots and placed into tins for proofing at room temperature for 1.5 hours. Tins were refrigerated at 4°C overnight before baking at 230°C for 35 minutes. After cooling the loaves were cellophane packaged and held at room temperature for 48 hours prior to sensory evaluation.

**Sensory assessment**

A total of twenty individuals participated in the sensory survey, gathered from a workshop to discuss end use function of perennial grains. Delegates were invited to the workshop based on their knowledge of perennial grains or their experience in the food industry. Demographic data was collected to capture the age, previous sensory experience, and smoking status of each participant. The sensory panel was designed so that participants were presented with a plate containing slices of all four sourdough bread samples, identified only by an alpha character (A, B, C or D). Each loaf had been sliced as evenly as possible by hand using a bread knife, with a half slice of each sample provided for rating. Participants were directed to the sensory assessment survey via a QR code on their mobile phone. Each participant was randomly allocated the order for assessing the four bread samples when they opened the survey. Instructions were given to participants to cleanse the palate between samples with water provided.

All responses were recorded electronically using SurveyMonkey®. Participants assessed each bread sample on four characteristics: appearance, aroma, texture and flavour. For each sensory attribute participants were asked to assign a star rating based on the following five options, “Dislike extremely”, “Dislike moderately”, “Neither like or dislike”, “Like moderately” or “Like extremely”. A single star option separated each major category to add greater precision in scoring and reduce the incidence of tied scores for a particular attribute, meaning that the maximum (positive) score that could be given by a participant for any given characteristic was 9. Participants were also asked “if you had to buy a loaf of one of the samples, which would you choose?” A final comment on each sample was also sought.

**Statistical analysis**

Participant responses were analysed using a linear mixed model in Genstat (20th Edition, VSN International). The fixed effects of sample, participant, previously on a sensory panel, age, smoking status and their interactions were tested. Insignificant terms were dropped from the model. The subsequent model included sample as the fixed effect and participant as a random term. All data was analysed at the 95% significance level ($P < 0.05$).

**Results and discussion.**

Most participants ($n=14$) in this study were inexperienced in participating in sensory assessments. The 41-50 age group ($n=7$) was the largest group in the survey with the older age group (50-60 and >60) having the next highest number of participants ($n=5$ in each category). One participant indicated as being a smoker (data not shown). There was no statistical bearing of demographic data on the outcomes of the survey.

Consumer perception of sensory quality is an important aspect of food choice. Although most consumers evaluate food quality by appearance, taste is also an important attribute which influences choice (Annett *et al.* 2008). There was less dough volume of each of the perennial wheat and
commercial wheat doughs due to the limitations in the amount of flour available. This may have impacted final fermentation of these doughs, resulting in altered texture of the test loaves, therefore giving an advantage to the population wheat which had no such limitation. The average star rating for appearance, aroma, and texture of the four bread samples are shown in Table 2. The population wheat entry was rated significantly higher for appearance, with 14 participants giving scores of 7 or above for this attribute. The remaining three bread samples had similar ratings for appearance. There was no statistical difference between bread samples for aroma, texture and flavour with average scores ranging from a low of 5.4 for Wedgetail and Ot-38 in texture (8 and 5 scores of ≥ 7, respectively) to 6.7 for aroma of the population wheat (14 scores ≥ 7). On average there were higher liking scores across sensory attributes for the loaf made from the population wheat compared to loaves produced from the perennial wheat breeding lines or the Wedgetail annual wheat cultivar. This was reflected in the response of participants to the question of which loaf they would most likely purchase (Figure 1). The overwhelming majority of participants (45%) indicated that they would purchase a loaf produced from the population wheat. The next likely choice were loaves produced from the perennial wheat cultivar Summer 1 and the commercial annual wheat Wedgetail, with 20% of participants indicating they would purchase this bread. Only 10% of participants indicated a purchase choice for the perennial wheat cultivar Ot-38, while one participant indicated they would not purchase any of the loaves on offer.

The perennial wheat cultivars had similar sensory scores for appearance, aroma, texture and flavour compared to the commercial wheat variety Wedgetail. This is an important finding as it suggests that the perennial wheat lines could be substituted for commercial wheat cultivars without any perceptible loss in sensory attributes in a sourdough loaf. There are complex interactions between wheat genetics and the growing environment, which influence sensory attributes in sourdough bread (Jones and Econopouly 2018). This effect cannot be discounted in the current study as the entries were grown in different areas (Table 1). Nevertheless, wheat genetics play a significant role in defining sensory characteristics.

**Table 4. Mean star rating scores (out of 10) for appearance, aroma, texture, and flavour for sourdough loaves made from the population wheat, commercial bread wheat cultivar Wedgetail and two perennial wheat lines Ot-38 and Summer 1 (ns= not significant). Values within a row with the same superscript are not significantly different (P>0.05).**

<table>
<thead>
<tr>
<th></th>
<th>Ot-38</th>
<th>Wedgetail</th>
<th>Population wheat</th>
<th>Summer 1</th>
<th>L.s.d (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>5.8a</td>
<td>6.2a</td>
<td>7b</td>
<td>5.9a</td>
<td>0.72</td>
</tr>
<tr>
<td>Aroma</td>
<td>6.2</td>
<td>6.1</td>
<td>6.7</td>
<td>6.4</td>
<td>(ns)</td>
</tr>
<tr>
<td>Texture</td>
<td>5.4</td>
<td>5.4</td>
<td>6.4</td>
<td>5.9</td>
<td>(ns)</td>
</tr>
<tr>
<td>Flavour</td>
<td>6.4</td>
<td>5.9</td>
<td>6.4</td>
<td>6.2</td>
<td>(ns)</td>
</tr>
<tr>
<td>Average across traits</td>
<td>5.97a</td>
<td>5.91a</td>
<td>6.65b</td>
<td>6.12a</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Therefore, selecting for these attributes in a perennial wheat breeding program would see improvement. Breeding for white flour yield has removed many of the traits associated with flavour and lowered the ash content in modern commercial wheat cultivars (Fan et al. 2008). Developing perennial wheat for sourdough production would need to improve traits for sensory attributes, along with agronomic traits, to ensure the new cultivars were developed to meet the specific needs of the end users.

Comments provided by participants were generally positive: “Very appealing flavours – complex and plum spice” (Ot-38), “Mild grassy herbal sweetness” (Wedgetail), “Delicious creamy caramel flavours” (Population wheat) and “Enjoyable. Should be in bakeries” (Summer 1). Other comments were less complimentary: “Bit gummy to eat” (Ot-38), “I was expecting this bread to be nicer than it
was, based on looks. I found the texture a bit drier than C and D” (Wedgetail), “Bit stodgy” (Population wheat) and “Little taste” (Summer 1). These comments provided further insight into the sensory performance of the four grain types under investigation as well as illustrating the diversity of tastes and preferences among the sensory panel.

Figure 2. Histogram of participant choice in response to the survey question “Which loaf would you most likely purchase?”

In this study the overall liking for the population wheat stood out compared to the other wheat entries, as indicated by the buying choice histogram (Figure 1). Population wheats are genetically diverse with individual plants distinct from one another compared to pure varieties in which individual plants are almost identical. This diversity is thought to create stability in production by buffering against biotic and abiotic stress for low input systems (Borg et al. 2018). However, this diversity would also impact sensory attributes as the mix of cultivars would impart different flavour and aroma traits to flour when baked in a sourdough. This would be an advantage over the stabilised pure lines as any detrimental characteristics could be overcome from the influence of other individuals in the population. In the short term, creating blends of different perennial wheat grains could be used as a strategy to overcome difficult sensory characteristics or end use performance, while these traits are being improved in a breeding strategy. Further research is required to experiment and develop the correct combination of cultivars in order to produce the desired product.

Another important aspect of sensory perception is the information given to the consumer during their evaluation of a product. For example, intermediate wheatgrass (IWG) is one of the first perennial cereal grains to become commercially available. In a recent study evaluating the sensory performance of sourdough breads made from blends of IWG, Homami (2020) reported a notable dislike of IWG based breads in terms of their appearance, taste and texture under blind tasting conditions. By comparison, wheat only control loaves were significantly higher in their liking scores. However, once participants were provided information about the environmental benefits of IWG before tasting, participants became more forgiving of sensory performance of the IWG breads. This had a flow on effect on the willingness of participants to purchase, with the IWG breads able to attract a premium price over the pure wheat control loaves. This was particularly evident among participants who valued environmental credibility. This suggests that marketing the “story” behind a new grain can raise the sensory perceptions amongst consumers and influence the profitability of a product entering the market. Perennial grain development offers a transformational change to current agricultural practice based on annual grain crops. The goal is to achieve environmental sustainability through improved resource-use efficiencies and maintaining food security without degrading the land resource which production relies upon. This goal has resonated with bakers, millers and processors who have trialled perennial grains in their business (see Sinclair et al 2021 in this proceedings).
Conclusion

The current study provides some of the first insights into the sensory performance of perennial wheat breeding material under development in Australia. For the most part, the perennial wheat lines performed as well as a commercial modern wheat variety for aroma, texture and flavour in sourdough loaves as assessed by the study participants. In terms of overall sensory characteristics, sourdough loaf made from the population wheat had the highest liking scores and was rated the preferred bread of purchase. Future breeding programs for perennial cereals will need to assess sensory and agronomic performance, to ensure that newly developed cultivars will meet the needs of end users. Emphasising additional information around the provenance and environmental credibility of new perennial grains will be important to help attract consumers to the product, with the potential to achieve a price premium. The 'population' approach to production to achieve crops with greater diversity of grain attributes is a concept that warrants further investigation in the development of early-generation perennial wheats.

References


Artisan baker assessment of sourdough loaves using perennial cereals: A preliminary study

Katrina Sinclair1,2, Sarah J. Baker3, Matthew T. Newell4,6 and Richard C. Hayes5

1 Wollongbar Primary Industries Institute, NSW Department of Primary Industries, Wollongbar, NSW 2477
2 Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW 2650
3 Tamworth Agricultural Institute, NSW Department of Primary Industries, Tamworth, NSW 2340
4 Agricultural Research and Advisory Station, NSW Department of Primary Industries, Cowra, NSW 2794.
5 Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW 2650.
6 Email: matt.newell@dpi.nsw.gov.au

Abstract

In Australia, in response to recent consumer demand for artisanal bakery products there has been an increase in the number of bakery enterprises producing small volumes of premium-priced products. Artisan bakers are using speciality grains and drawing on traditional techniques to develop products with unique characteristics and nutritional benefits which meet the demands of their customers. Perennial cereals currently being evaluated for their agronomic potential may be a valuable grain for use by artisan bakers in developing products with distinctive flavours and strong sustainability credentials. The aim of this preliminary study was for artisan bakers to assess the baking attributes of sourdough bread using selected perennial grains and a commercial bread wheat. Tinned or hearth sourdough loaves were produced by four experienced artisan bakers from milled perennial wheat derivatives including Ot-38, OK72, 235a, 20238, Summer 1 and 11955, as well as mountain rye (Secale montanum Guss.) and the commercial wheat cv Wedgetail. Each baker assessed the volume, external appearance, colour, crumb texture and flavour of the loaves they produced. In assessing the overall performance, almost all bakers assessed Summer 1, mountain rye, 11955, 235a and OK72 as being “market ready”. Lines OT-38 and 20238 were not considered “market ready”. However, given the preliminary nature of the study, further testing is required to fully examine the market potential of each assessed line. In conjunction with further agronomic development of these grains, we suggest that flavour should be included as an important selection trait to capture their potential use in the expanding artisanal market.

Key words: Specialty, appraisal, bread, grain

Introduction

In Australia, the recent consumer trend away from traditional and processed products has seen a rise in the consumption of artisanal products including bread and craft beer (IBISWorld 2021). In response to increased demand, there has been an increase in the number of bakery enterprises producing small volumes of hand-crafted, premium-priced products. Consumers with high disposable incomes are the major purchasers of artisanal bread with the artisan bakers relying on a loyal customer base to support their business enterprise (IBISWorld 2021). To maintain their customer base, the artisan baker needs to understand the values held by their customers. These values include health benefits, environmental concerns, unique flavours and product provenance.
Artisanal bakery products are typically made using traditional techniques including a long fermentation period in contrast to the high throughput techniques used in factory-made products. For example, artisanal sourdough loaves are produced using basic ingredients including stone or roller milled flour, water and salt with no artificial additives. The fermentation process uses naturally occurring yeasts and bacteria to develop different styles of products. Artisan bakers are seeking to develop products that are unique by using specialty grains including heritage wheats and sprouted grains - a key factor in developing a point of differentiation is the development of bread with distinctive flavours. Although recent studies have begun to investigate the grain quality attributes of some perennial wheat breeding lines (Murphy et al. 2009; Hayes et al. 2012: Tang et al. 2021), there has been little research effort devoted to understanding the value these grains may offer the artisan bakery market.

In NSW, a range of perennial cereals are currently being evaluated for their forage and grain potential (Newell and Hayes 2017). To justify their use by artisan bakers, it is critical that perennial grain breads have pleasing flavours and desirable colours as well as good volume, acceptable appearance and moist crumb texture. The aim of this study was for artisan bakers to assess the baking attributes of sourdough bread using selected perennial grains or a commercial bread wheat.

Methods

A two-part survey instrument was developed for the artisan bakers in the study. In Part 1, background information was gathered about the artisan’s baking experience and business enterprise. In Part 2, information was sought from the artisan bakers about their assessment of the product they had produced from one of a set of perennial lines or a commercial wheat cultivar. The bakers’ assessed the external and internal characteristics of their product using a rating scale provided. Other information gathered in this section included a description of the process the artisan baker used and their view about various aspects of the grain when used for baking (see Appendix in this Proceedings for a copy of the survey instrument).

Artisan baker participants

The four artisan bakers who participated in the study had been in the industry for at least 5 years and were experienced in using different types of cereal grains (Table 1). These bakers were also experienced in producing sourdough bread.

<table>
<thead>
<tr>
<th>Artisan baker</th>
<th>Years in industry</th>
<th>Experience with specialty grains</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10-20</td>
<td>Spelt, rye and population wheats</td>
</tr>
<tr>
<td>2</td>
<td>10-20</td>
<td>Modern wheat, heritage wheat and cereal rye</td>
</tr>
<tr>
<td>3</td>
<td>5-10</td>
<td>Spelt, emmer wheat, rye, sprouted grains and korshan wheat</td>
</tr>
<tr>
<td>4</td>
<td>5-10</td>
<td>Modern wheat, heritage wheat and cereal rye</td>
</tr>
</tbody>
</table>

Grain type, milling and baking

The seven perennial grain types used were 11955, 235a, Ot-38, OK72, Summer 1, 20238 and mountain rye together with the commercial cultivar, Wedgetail (Table 2).
Table 2. Pedigree and origin of perennial lines and commercial line for testing

<table>
<thead>
<tr>
<th>Entry</th>
<th>Pedigree</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>11955</td>
<td><em>Triticum aestivum</em>/Thinopyrum ponticum</td>
<td>USA</td>
</tr>
<tr>
<td>235a</td>
<td><em>T. aestivum</em> (CS)/Th. elongatum/<em>T. aestivum</em> (M)</td>
<td>USA</td>
</tr>
<tr>
<td>Ot-38</td>
<td><em>T. aestivum</em>/Th. intermedium</td>
<td>Russia</td>
</tr>
<tr>
<td>OK 72</td>
<td><em>T. aestivum</em>/Th. ponticum</td>
<td>USA</td>
</tr>
<tr>
<td>Summer 1</td>
<td><em>T. aestivum</em>/Th. intermedium</td>
<td>China</td>
</tr>
<tr>
<td>20238</td>
<td><em>T. durum</em>/Th. elongatum</td>
<td>Mexico</td>
</tr>
<tr>
<td>mountain rye</td>
<td>Secale montanum</td>
<td>Australia</td>
</tr>
<tr>
<td>Wedgetail</td>
<td><em>T. aestivum</em> common bread wheat</td>
<td>Australia</td>
</tr>
</tbody>
</table>

CS = Chinese Spring
M = Madsen

Apart from mountain rye there were insufficient quantities available for the four bakers to produce a sourdough loaf for each of the seven perennial grains. The grain samples were randomly allocated to the bakers for testing (Table 3). The number of sourdough loaves produced for each grain is as follows: mountain rye (n=4); 235a, Ot-38, OK72 and Summer 1 (n=3); 11955, 20238 and Wedgetail (n=2). The bakers were able to choose either a free formed hearth or tinned loaf. In producing a hearth loaf the dough must have sufficient strength to hold the shape of the loaf whereas a tin provides support for the dough.

Table 3. Type of sourdough loaf produced and grain allocations to the artisan bakers

<table>
<thead>
<tr>
<th>Artisan baker</th>
<th>Sourdough loaf type and grain type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tinned loaf-235a, Ot-38, OK72, 20238</td>
</tr>
<tr>
<td></td>
<td>Hearth loaf-mountain rye</td>
</tr>
<tr>
<td>2</td>
<td>Tinned loaf-mountain rye</td>
</tr>
<tr>
<td></td>
<td>Hearth loaf-Ot-38, OK72, Summer 1, 20238</td>
</tr>
<tr>
<td>3</td>
<td>Tinned loaf- mountain rye</td>
</tr>
<tr>
<td></td>
<td>Hearth loaf-11955, 235a, Ot-38, OK72, Summer 1, Wedgetail</td>
</tr>
<tr>
<td>4</td>
<td>Tinned loaf-11955, 235a, Summer 1, Wedgetail</td>
</tr>
<tr>
<td></td>
<td>Hearth loaf-mountain rye</td>
</tr>
</tbody>
</table>

The process used for milling the grain, dough making and baking the sourdough loaf was left to the discretion of the individual artisan baker. Bakers 1, 3 and 4 used a stone mill while baker 2 used a roller mill to produce the flour from the grain. The four bakers used their bespoke method for dough making and baking.

Assessment of baking performance

Subjective assessments were made by the four bakers on the quality of the sourdough loaf they produced using the selected grain. The external characteristics assessed were external appearance and loaf volume. The internal characteristics assessed were crumb texture, colour and flavour. The qualitative assessments of each loaf produced were based on a 4-scale rating: very good, good, acceptable and poor. The data for each grain type, irrespective of loaf type and artisan baker, was combined to provide a summary of the grains’ performance for each characteristic. In addition, the bakers rated the overall baking performance of the selected grain: “ready to market”, “needs more work” or “not worth pursuing”.

Proceedings of the Perennial Artisan Grain Workshop, 15 – 17 June 2021, Cowra, Australia © 2021
42
Findings

The bakers’ assessments of the loaf volume and external appearance of their sourdough loaves using the different grain types are shown in Figures 1a and 1b, respectively. The bakers’ assessments of internal colour, crumb texture and flavour of their sourdough loaves are shown in Figures 1c, 1d and 1e, respectively.

Each of the bakers rated their mountain rye (n=4) loaf very good for external characteristics while three bakers rated the internal characteristics as very good. As an example, Baker 4 provided the following description. The loaf had a “dark golden bran” with “attractive surface cracking”. It had a “delicious, sharp, sour, tangy” flavour. “A classic rye loaf well sprung (for a rye) and a less dense crumb than the usual rye loaves I bake.”

Only one of the bakers rated their Summer 1 (n=3) loaf very good for external characteristics, two bakers rated colour and crumb texture as very good and one baker rated flavour as very good. As an example, Baker 3 provided the following description. The loaf was a “very light yellow. Texture was smooth. The flavour was indistinguishable, fairly unpronounced. [It had a] ‘reasonable performance all round’.”

The ratings of the internal and external characteristics of 235a (n=3) by the bakers were variable. As an example, Baker 4 provided the following description. The “golden bran was very attractive. [It was] not as well sprung needing more hydration”. The flavour was “intensely nutty with a slight bitter edge to it”.

Only one of the bakers rated their OK72 (n=3) loaf very good for appearance and, likewise, for volume. The rating of the internal characteristics by these bakers was somewhat variable. Flavour was rated by the three bakers as good. As an example, Baker 1 provided the following description. There was a “good even shape to the loaf with evenly textured crust, decent volume, light enough crumb structure. Herbal flavours like rosemary, some honey-like sweetness”.

The bakers rated the external appearance of Ot-38 (n=3) as good and, likewise for volume. One baker rated the colour, crumb texture and flavour as very good. As an example, Baker 2 provided the following description. The “crumb had a light brown colour. Good flavour. One of the nicest. A little rise in the oven”.

Baker 3 rated the external characteristics of their 11955 (n=2) loaf as acceptable while Baker 4 rated these characteristics as good. The two bakers rated the crumb texture as good. Baker 3 rated colour as good and Baker 4 as acceptable. Neither baker provided a rating for flavour although Baker 3 described the flavour as “grassy”. Baker 3 further described the loaf as having a “deep colouring. Good texture. Consistent crumb”. Baker 4 described the loaf as being “well sprung (it was well hydrated) but the grey tinge of the loaf didn’t appeal to me”.

The bakers rated their 20238 (n=2) loaf as acceptable for volume, appearance, and colour. Baker 1 rated the crumb texture and flavour as acceptable while Baker 2 rated these characteristics as poor. Baker 2 described the loaf as “gummy, tacky and weak to shape. It would tear. Crumb was not good...flavour more bitter. Not that enjoyable...Ordinary in strength, fermenting, baking and flavour”. Baker 1 found “the flavour well developed, and the texture had a good chew...The dough was, however, quite unstable and could not absorb much water to lighten the baked crumb texture further...for a more pleasant mouthfeel”.

Baker 4 rated the internal and external characteristics of their Wedgetail loaf (n=2) as very good while Baker 3 rated these characteristics as acceptable. Baker 4 described the loaf as being “well sprung with an open crumb. The flavour was nutty, milder and sweeter than the others [tested]”. Baker 3 found “Wedgetail had slightly poorer performance in areas of taste, loaf volume and appearance”.

Proceedings of the Perennial Artisan Grain Workshop, 15 – 17 June 2021, Cowra, Australia © 2021
Figure 1f provides the bakers’ assessment of the overall baking performance of the grains. Most bakers assessed Summer 1, mountain rye, 11955, 235a and OK72 as “market ready”. As an example, Baker 4 explained:

“This [mountain rye] is my favourite of all the test flours. Exceeded my expectations.”

Of the remaining grains, Ot-38 was assessed by two of the three bakers as “needs more work”. The grain 20238 was assessed as either “needs more work” or “not worth pursuing” by the two bakers who tested this grain. Wedgetail was assessed as “ready to market” by one baker and “needs more work” by the other baker.

**Discussion**

The study has shown that selected perennial cereal grains currently under agronomic evaluation in Australia can be utilised by artisan bakers to produce a high-quality product. The artisan bakers indicated their interest in perennial grains related to their (and their customers) views around sustainable production of food in a changing climate. As Baker 4 explained:

“We see perennial grain as a hopeful, more sustainable, financially, environmentally, holistic approach to growing food in this era of rapid climate change and a tool to sequester carbon.”

These bakers are already using speciality grains for diversity and flavour. They use their experiential knowledge to adjust their milling, dough-making and baking practices to achieve the desired characteristics in their product. As Baker 1 explained:

“We mill spelt, rye and population wheats to bring fresh flours into the bakery. They each have different milling protocols according to grain softness and size. All are sourced directly off farm. Hence, there is strong seasonality to consider when milling and baking these grains...We find most challenges can be overcome with different dough making processes.”

Although the perennial grains, Summer 1, mountain rye, 11955, 235a and OK72 were rated as “ready to market”, the Ot-38 loaf was also rated highly for its flavour. Flavour is recognised as fundamental to the acceptance of or preference for a product by consumers (Clark 1998). A key attribute for artisan bakers is for their products to have a flavour that their customers find pleasing. The use of the grain 20238 appears to be problematic in its inability to produce a stable dough for a hearth loaf and to absorb sufficient water to improve the texture of the crumb. This may be associated with its durum wheat parentage and may not preclude it from use in other baked products such as crackers.
Figure 1. Bakers rating. Very good, Good, Acceptable or Poor, of sourdough loaves produced from mountain rye (n=4); Ot-38, OK72, 235a and Summer1 (n=3); 20238, 11955 and Wedgetail (n=2) for a) external appearance, b) loaf volume, c) colour, d) crumb texture, and e) flavour. In addition, a rating for overall baking performance, Ready to market, Needs more work or Not worth pursuing is presented in f). All entries are ranked lowest to highest for each attribute and baking performance based on participant responses.
Conclusion

The assessment of the sourdough bread using milled perennial grains indicated their potential as a speciality grain in products for human consumption. A key point of difference in the marketability of perennial grains compared to other specialty grains is the story behind the grain: the ability of the plant to perenniate and have a smaller environmental footprint compared to conventional cereal plants. Common among artisan bakers is the ability to adjust their processes to make a bread or different baked products that are suitable for perennial grains.

The study provided evidence of the subjective nature in assessing food products. Although the artisan bakers in the study each had extensive experience in producing sourdough bread, there was, with some lines, considerable variation in their assessment of the external and internal characteristics. This is no different from consumers in making a food choice. It highlights the need to conduct consumer testing as well as standard objective assessments of the grains for the artisan industry. The assessment of the conventional wheat, Wedgetail, by one experienced baker as requiring “further work” illustrates the inadequacy of objective assessments to fully capture all the traits that artisan bakers consider important.

The study also provided evidence that a number of perennial grain lines presently under investigation could be made available immediately to the artisan market. Given the limited nature of the study, we suggest that it is important at this stage in the development of this emerging industry that all current perennial grain lines are retained for further testing. We also suggest that flavour should be included as an important selection trait in further developing perennial grains material.

Acknowledgments

The authors would like to thank the four bakers for their time to produce the sourdough loaves and then to assess their baking performance. We appreciate their passion and commitment to their craft and for their interest in the development of perennial grain crops.

References


A brewer’s assessment of beer made using perennial grains

Sarah J. Baker1, Katrina Sinclair2,3, Richard C. Hayes4 and Matthew T. Newell5,6

1 Tamworth Agricultural Institute, NSW Department of Primary Industries, Tamworth, NSW 2340
2 Wollongbar Primary Industries Institute, NSW Department of Primary Industries, Wollongbar, NSW 2477
3 Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW 2650
4 Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW 2650
5 Agricultural Research and Advisory Station, NSW Department of Primary Industries, Cowra, NSW 2794
6 Email: matt.newell@dpi.nsw.gov.au

Introduction

There is a growing trend among Australian consumers to select craft beer products in favour of mass-produced beers. The origin, provenance and story of how a beer is produced is becoming increasingly important in the craft beer market and smaller niche brewers have capitalised on the growing demand for locally produced beers (IBISWorld 2020). Consumers of craft beer have a high disposable income with a willingness to pay a premium for products with unique flavours, reduced environmental impact and product provenance.

Wildflower Brewing & Blending (WBB) is a small-scale brewery based in Sydney. The brewer has been working in the industry for more than five years producing beer products sold at the cellar door; to restaurants, cafes and bottle shops, and online. WBB’s main products are made with 60-84% malted barley with smaller amounts of wheat, cereal rye, triticale and spelt grains making up the remainder. The speciality grains are used raw in the grist to impart novel flavours. Malted barley is required for a successful fermentation with WBB using native yeasts as the fermenting agent. The brewery sources almost its entire grain supply from a “regenerative organic” farm in southern NSW.

A range of perennial cereals are being evaluated in NSW for their potential use as a forage for livestock. There is, however, unexplored potential for the grain to be used in products for human consumption. This pilot study enabled a craft brewer, Wildflower Brewing & Blending, to assess the potential of including perennial grains in their brewing of craft beers.

Methods

Twenty kilograms of grain from each of three perennial cereal lines, (235a, 11955 and mountain rye) were supplied to WBB to produce craft beer (refer to Newell et al. 2021 in these proceeding for more detail about the grains). The lines, 235a and 11955 were wheat x wheatgrass derivatives whereas mountain rye is a perennial relative of cereal rye. The brew style used for each of the grains was Australian wild ale. A blend consisting of 20-30% unmalted perennial grain with the remainder comprising malted barley was used. The resultant brews were barrel fermented, aged and bottle conditioned before evaluation by the brewer.

The WBB brewer made subjective assessments on each of the three wild ales produced from the perennial grains. Four attributes of the brewed beers, aroma, taste, mouth feel and colour, were assessed using a 4-scale rating: very good, good, acceptable and poor. The brewer also provided an assessment of the overall performance of the products: ready to market, needs more work or not worth pursuing further.
Findings

The brewer’s assessment of attributes for aroma, taste, mouthfeel and colour of the brewed Australian wild ale using the three grain types is shown in Figure 1. The two hybrid perennial wheats, 235a and 11955, were rated either as very good or good for the four attributes. For mountain rye, aroma, mouthfeel and colour were rated as good, with taste rated as acceptable.

The brewer provided a sensory evaluation for each of the ales produced using the three grains. The descriptors that mostly relate to aroma, taste and mouthfeel are provided below for each grain.

The ale using 235a was described as:

“Most citrus and gold like. Lemon curd. Sweet biscuity spice (Anzac biscuits ~golden syrup/caramel). Lemonade, sprite palate. Balanced palate bitterness. Less body than other two [11955 and mountain rye], feels fresher and zippier.”

The ale using 11955 was described as:

“Touch SO2[sulphur dioxide]/cabbage. Blows off quickly. Strong earthy grainy nose. Herbal (lavender like) cake batter with sweet cooking spice. Palate has good body, supple. Touch sweetness (maybe factor of the low carb[onation]/referm[entation]). Dusty (coming from grain) lemon. Sugar Biscuit. Short palate but enjoy the flavours.”

The ale using mountain rye was described as:


In assessing the overall performance of the grains in producing the Australian wild ale, the brewer rated 235a and 11955 as market ready, while mountain rye required more work.
Discussion

The WBB brewer valued the “spice” flavour and “mouth feel” of all three of the perennial grains, although mountain rye was marked down on taste and this may reflect its evident bitterness. However, craft brewers like other producers of artisan grain products are able to adjust their processes enabling them to successfully use a diverse range of cereal grains (refer to Sinclair et al. 2021 in this proceedings).

For WBB, of most interest was “the story and agriculture behind...” the development and production of a perennial cereal plant which distinguishes it from traditional cereal plants. In their view, the potential to use perennial grains in their products is “a way of highlighting the work being done in the agricultural sector and the potential for this sector to really be leaders of a more sustainable future”.

In the current assessment, all three grains were added as a percentage to malt barley in the production of ale. Although these grains have the potential to provide unique flavours to craft beer, an understanding of the malting characteristics of the grain would provide further insights as to the usefulness of these grains in the craft brewing industry. To pursue malting accreditation would enable a large up-take of these grains by brewers and, in so doing, increasing the market demand for perennial grains. As the WBB brewer explained: “For them [perennial grains] to be seriously considered in the brewing market, we would need to trial malting them.” There may also be an opportunity to use other fermentation processes including Koji spore to impart different flavour profiles with perennial grains to derive different brewing and distilling products for the industry.

Conclusion

Perennial grains gave the ale unique flavours which is a key attribute in the craft beer market. There is an opportunity for perennial grains to be used by craft brewers to create boutique beers that have an “environmental sustainability” story. Further testing by a larger number of brewers is warranted to fully appraise the potential of perennial cereals in craft beer. However, these initial results are promising with further opportunities possible if malting accreditation is pursued.

Acknowledgement

The authors would like to thank the WBB staff for their time to produce the Australian wild ales and then to assess their performance. We appreciate their passion and commitment to their craft and for their interest in the development of perennial grain crops.

References


Assessing the potential of perennial cereals in processing food products

Sarah J. Baker¹, Katrina Sinclair²,³, Richard C. Hayes⁴ and Matthew T. Newell⁵,⁶

¹ Tamworth Agricultural Institute, NSW Department of Primary Industries, Tamworth, NSW 2340
² Wollongbar Primary Industries Institute, NSW Department of Primary Industries, Wollongbar, NSW 2477
³ Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW 2650
⁴ Wagga Wagga Agricultural Institute, NSW Department of Primary Industries, Wagga Wagga, NSW 2650
⁵ Agricultural Research and Advisory Station, NSW Department of Primary Industries, Cowra, NSW 2794
⁶ Email: matt.newell@dpi.nsw.gov.au

Introduction

Australian consumers are becoming increasingly aware of and concerned about health and nutrition. In response, the larger cereal processing companies are adding products to their portfolios that focus on whole grains which carry positive health benefits and less higher risk nutritional components such as high saturated fat, sodium (salt) and sugar (IBISWorld 2021). Perennial grains have demonstrated superior nutritional properties compared to modern cultivated wheat and contain many health claimable properties (Gazza et al. 2021). This provides an opportunity to use perennial cereals in manufactured products with improved nutritional qualities.

The well-known Australian breakfast cereal brand, Uncle Toby’s, is owned by Cereal Partners Worldwide, a partnership between Nestlé and General Mills. The company has been producing breakfast products for more than 125 years using oats, wheat, corn and rice. More than 50 breakfast cereals are produced by the brand for the Australian market, as well as snack foods including muesli bars. The national Health Star Rating (HSR) provides a food labeling system which identifies the nutritional profile of packaged goods in Australia and assigns a rating from 0.5 to 5 stars. The increasing number of stars identifies healthier food choices. All Uncle Toby’s produced cereal products carry a 4-star rating, which distinguishes their product in the market. These products are sold through the major supermarket chains and online.

Perennial cereals have scarcely been assessed for their suitability in manufactured food products such as breakfast cereals and muesli bars. In this study, samples of a range of perennial cereal grain were provided to the Uncle Toby’s company to undertake initial testing at their Wahgunyah R&D Pilot Plant facility.

Methods

Depending on availability, 30 – 100 kg of eight breeding lines (entries) were provided to the Product Development Team at Uncle Toby’s (Table 1). These included five wheat x wheatgrass hybrids (11955, 235a, Ot-38, OK72, Summer 1) as well as mountain rye, and intermediate wheatgrass (IWG). The latter two entries are perennial grass candidates undergoing domestication to produce perennial grain cultivars. A commercial annual wheat (Wedgetail) was provided as a comparison.
Table 1. Pedigree and origin of perennial lines and commercial wheat line entries used for testing.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Pedigree</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>11955</td>
<td><em>Triticum aestivum/Thinopyrum ponticum</em></td>
<td>USA</td>
</tr>
<tr>
<td>235a</td>
<td><em>T. aestivum</em> (CS)/<em>Th. elongatum/T. aestivum</em> (M)</td>
<td>USA</td>
</tr>
<tr>
<td>Ot-38</td>
<td><em>T. aestivum/Th. intermedium</em></td>
<td>Russia</td>
</tr>
<tr>
<td>OK72</td>
<td><em>T. aestivum/Th. ponticum</em></td>
<td>USA</td>
</tr>
<tr>
<td>Summer 1</td>
<td><em>T. aestivum/Th. intermedium</em></td>
<td>China</td>
</tr>
<tr>
<td>IWG</td>
<td><em>Th. intermedium</em></td>
<td>USA</td>
</tr>
<tr>
<td>mountain rye</td>
<td><em>Secale montanum</em></td>
<td>Australia</td>
</tr>
<tr>
<td>Wedgetail</td>
<td><em>T. aestivum</em></td>
<td>Australia</td>
</tr>
</tbody>
</table>

CS = Chinese Spring  M = Madsen  IWG = Intermediate wheatgrass

Each entry was run over a gravity table to remove any grain which had retained the lemma and palea portions of the kernel. The clean grain samples were then steamed and rolled to between 0.8 – 1.0 mm in thickness, using the processor’s protocol to produce rolled oats, with adjustments for each grain type. A further sub sample of Summer 1 grain was batch cooked via steaming for a longer period to gelatinise the starch. These were then flaked by rolling to 1 to 1.2 mm thickness. This test enabled assessment of production for breakfast cereal flakes. Due to time constraints only one entry was able to be tested.

The processed grains were assessed by the Product Development Team for the following attributes: flake integrity, flake size, flake texture, colour, and flavour using a four-point scale: very good, good, acceptable and poor.

Findings

Grain profiles and cross sections of the eight test grains demonstrated the lower endosperm content of the perennial grains when compared to the conventional annual wheat Wedgetail (Figure 1). Grain shape and depth of the crease impact flake integrity from rolled grains, as this reflects the proportion of endosperm compared to other grain components for a particular grain. The flakes produced by some of the hybrid grains were initially “less well adhered” during processing. However, after some experimentation, adjustment to the steaming and rolling conditions was made to reduce “flake crumbliness”. Following this, all eight grain entries were able to produce flakes either through steaming and rolling, or in the case of Summer 1, batch cooking and rolling. All perennial grain entries produced similar results to the conventional wheat control entry. The characteristics of flake integrity, texture, colour and flavour all achieved a rating of good on the four-point scale. As all grains tested were generally smaller than other grains used in the plant (oats, corn) the flake size was rated as acceptable. Some fine tuning of the batch cooking protocol is warranted as the attempt with Summer 1 produced a light-coloured flake, which suggested it was under cooked. Flakes which are brown in colour are more acceptable to consumers.

The performance of mountain rye and IWG were a standout from the other grains tested. Both grains were small in size by comparison, however, their flake integrity was strong due to a relatively shallow crease in the rolled grain (Figure 1). The Product Development Team explained “[IWG] and mountain rye were small grains, but we managed to roll a good looking (if somewhat small) rolled grain”. The IWG grain produced an “interesting colour”. During the processing the team noted the grains had a “much more malty nose to them” compared to oats or wheat, noting “[mountain] rye had the best (malty distinctive flavour)”.  

Proceedings of the Perennial Artisan Grain Workshop, 15 – 17 June 2021, Cowra, Australia © 2021
Discussion

Overall, the rolling of perennial grains was considered successful, and, in the view of the Product Development Team, there was potential to include these perennial grains in Uncle Toby’s products. They explained:

“Given how the grain rolled, I am confident we could use these grains (perhaps diluted down with standard wheat or oats) in all forms of breakfast cereal. Nutritious snack bars would also be another potential place they could be used.”

Most consumers purchasing manufactured food products are more price sensitive and less willing to pay premium prices for standard supermarket products, compared to those consumers purchasing artisan products (Sinclair et al. 2021). Market research currently indicates consumer’s product choices, through supermarkets, are more influenced by price, flavour and health benefits, but there is a growing interest in environmental impact (Uncle Toby’s, pers. com.). The improved nutritional qualities of perennial grains may provide a point of difference compared to conventional grain used in breakfast cereals and “may allow some nutritional claim”. However, at a company level, agricultural sustainability is a key factor in decision making. For example, General Mills recently committed to assisting in commercializing the perennial grain, Kernza® (IWG), in the United States. This aligned with the company’s commitment to land stewardship, “creating a positive relationship between the food and the land from which it is produced” (General Mills, 2019). For Uncle Toby’s, the change in company values towards sustainable agriculture is central to their interest in perennial grains. While the hybrid perennial grains have greater productivity and larger grain size, their reduced persistence is a detriment to their use at their current stage of development. The true perennials are where the interest lies, as the Product Development team explained:

“If our goal is to move to a more sustainable regenerative agricultural system then if I’ve got a hybrid where I’ve still got to plough it in every year or maybe every second year then I’m not actually delivering the sustainability benefit that I would get out of [IWG] or mountain rye.”

An immediate opportunity for the company to use rolled perennial grains would be in porridge, muesli and health bars. The Product Development team believed that the unique colour of the rolled IWG grain would be highly visible (making the product attractive) and would help in promoting “the sustainability story”, as they explained:

“... the first golden opportunity would be just rolled incorporated in a porridge to talk about sustainability ... and that way they are much more visible. If I put some [IWG], for example, in with some oats you would see them stand out.”

Other possible uses identified by the Product Development Team included milling into a flour and in extruded products. There would be some challenges with a smaller grain size as the manufacturing equipment would require modification. For large manufacturing companies to develop viable products from perennials, grain price would need to be equivalent to that of wheat. The volume they could potentially use would be “in the 1,000’s of tonnes (wild guess between 1,000 – 4,000 tonnes annually).” Grain yields of perennial cereals are often lower than conventional grains (Hayes et al. 2012), however, if the yield could be improved allowing the price per tonne to be lower, then these grains could be incorporated into the grain base used by Uncle Toby’s. As a manufacturer producing large volumes of cereal products to Australian supermarkets, they are limited by the demands of the supermarket and their customer base. Uncle Toby’s explained their position:

“Whilst consumers are interested in supporting sustainable agriculture, there is a limit to the premium that they will pay on the standard supermarket shelf. Given this constraint [higher] grain yield will be needed to give viable returns to farmers.”
Figure 1. Examples of grain profile, internal cross section and flakes produced from hybrid perennial cereals (11955, 235a, Summer 1, Ot-38, OK72), mountain rye, intermediate wheatgrass (IWG) and an annual wheat (Wedgetail). Arrow indicates flakes produced from batch cooked grain prior to rolling. Images courtesy of Uncle Toby’s, not to scale.
Conclusion

The perennial grains assessed in this study proved suitable for rolling and flaking, opening the opportunity for inclusion as a component of breakfast cereals and health bars. Uncle Toby’s values sustainable agriculture and sees perennial grains as aligning with this value. Consumers increasingly seek nutritious foods and the processor believes they could include perennial grains in porridges, mueslis and health bars to meet this demand. The use of perennial grains such as IWG and mountain rye could be incorporated immediately into products while transitions are made to improved cultivars. The continued development of hybrid perennial grains for greater persistence would see their inclusion in manufactured products in the longer term.

Acknowledgment

The authors would like to thank the Uncle Toby’s Product Development Team for their time in processing the grains and then to assess their performance. We appreciate their interest in the development of perennial grain crops.

References


The effects of growing conditions on grain quality characteristics and functionality of Australian-grown perennial wheat

Ke Hong Tang1, Annie Riaz2, Denise Pleming3, Matthew Newell4, Matthew Wilson1, Richard Hayes3, Chris Blanchard2,5 and Beth Penrose1.

1 Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 98, Hobart, TAS. 7001, Australia
2 ARC ITTC for Functional Grains, Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga, NSW 2678
3 NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, Pine Gully Road, Wagga Wagga, NSW 2650
4 NSW Department of Primary Industries, Agricultural Research and Advisory Station, Cowra, NSW 2794
5 Email: cblanchard@csu.edu.au.

Abstract

Perennial grains offer a choice for farmers and consumers who seek alternative grains which may be grown using more sustainable farming systems. However, to maximise their commercial viability, all grains require specific functional properties to ensure they are suitable for use as ingredients in food processing applications. To enable perennial grain cultivation to become commercially viable, a clear understanding of the impact of genetic and environmental factors on grain composition and food processing properties is required. This paper examines the functional properties of grain from a range of perennial lines grown in various locations over two seasons. Some preliminary rheology studies were conducted on whole grain flour samples to evaluate the potential breadmaking properties of the different genotypes. A preliminary study on the impact of genetics and environment on grain dimensions, composition and food processing applications were undertaken. The results demonstrated that grain from some perennial lines showed good potential as food ingredients. While environmental factors impacted on the functionality of the grains, in some cases the perennial grains were more resistant to environmental impacts than conventional wheat lines.

Introduction

Perennial wheat is a promising alternative to annual wheat for use in both the food and livestock feed industries. There are numerous advantages to sowing perennial grains; primarily the improved resource-use efficiency attributable to longer growing seasons (Zhang et al., 2011), reduction in nitrogen leaching and soil erosion due to increased soil cover (Cox et al., 2010). Also, perennial species often have deeper root systems (Shi et al., 2011), although this can be at the expense of grain yield at least in the establishment year. Perennial crops provide more than one product that can be harvested from a given amount of input, including grain and grazing forage (Ryan et al., 2018). In contrast to annuals, a large portion of assimilated carbon in perennial species is invested in developing an extensive root system and more vegetative biomass (Lloyd, 2015; Newell and Hayes, 2018). These traits offer environmental and sustainability advantages over annual wheat in agricultural systems (DeHaan and Ismail, 2017), which, in a world where sustainability is a major consumer trend (Forbes, 2020), could provide distinct competitive advantage. However, full commercial value will only be realised with better understanding of the grain characteristics and functional properties of perennial wheat, and the influence of growing conditions on these qualities. This paper investigates some of the
Materials and methods

Experimental sites

Perennial wheat grain used for this study was harvested in 2018 from experimental sites located in Cowra (hereafter Cowra A) and Mandurama; and in 2019 from sites in Cowra (a different site to 2018, hereafter Cowra B) and Orange in New South Wales (NSW), Australia. Trials were established as small plots (2 × 7.5 m) in randomised block designs with three replicates and were grown under rainfed conditions except Cowra B which had additional irrigation from the period of flowering until harvest. Conditions during 2019 were drier than in 2018, especially in spring, although minimum and maximum temperatures recorded in all experimental sites were similar.

Germplasm

Seven hybrid perennial wheat genotypes derived from crosses between annual wheat and wheatgrass sp. (Agropyron spp., A. elongatum, Thinopyrum elongatum, Th. intermedium, Th. ponticum), one annual wheat (Triticum aestivum) cv. Wedgetail and one triticale cv. Endeavour (an annual) were included in this study (Table 1).

<table>
<thead>
<tr>
<th>ID</th>
<th>Pedigree</th>
</tr>
</thead>
<tbody>
<tr>
<td>11955</td>
<td>Triticum spp./Agropyron spp. hybrid</td>
</tr>
<tr>
<td>CPI-147235a (235a)</td>
<td>T. aestivum (CS)/Thinopyrum elongatum/T.aestivum (M)</td>
</tr>
<tr>
<td>20238</td>
<td>T. durum (S)/A. elongatum</td>
</tr>
<tr>
<td>OK7211542 (OK72)</td>
<td>Partial amphiploid derived from T. aestivum/Th. ponticum</td>
</tr>
<tr>
<td>Summer 1</td>
<td>Partial amphiploid derived from T. aestivum/Th. intermedium</td>
</tr>
<tr>
<td>CPI-147251b (251b)</td>
<td>T. aestivum (CS)/Th. elongatum/T.aestivum (M)</td>
</tr>
<tr>
<td>Otrastajusecja 38 (Ot-38)</td>
<td>Partial amphiploid derived from T. aestivum/Th. intermedium</td>
</tr>
<tr>
<td>Wheat cv. Wedgetail</td>
<td>T. aestivum</td>
</tr>
<tr>
<td>Triticale cv. Endeavour</td>
<td>× Triticosecale</td>
</tr>
</tbody>
</table>

Chinese Spring (CS) and Madsen (M) are cvv. of T. aestivum; Stewart (S) is a cv. of T. durum

Grain morphology, weight and colour

Grain length and width were measured using digital callipers on three randomly selected grains from each replicate plot. Length was measured from the germ to the brush end of each kernel, and width was measured from dorsal side to the ventral or (crease) side (DV) and from left to right (LR) of each kernel. One hundred grains of each genotype were counted and weighed using a seed counter (Contador, Pfeuffer GmBH, Denmark) and the mass was multiplied by 10 to ascertain thousand kernel weight (TKW). Colour was measured in triplicate using a colourimeter (Chroma Meter CR-400, Minolta, Japan) and reported in CIE colour space L* a* b* where L* represents brightness, a* greenness (-ve) to redness (+ve), and b* blueness (-ve) to yellowness (+ve).
Grain protein and total starch content

Grain (5 g) from each replicate plot was prepared using a ball mill (Mixer Mill MM200, Retsch, Germany), which was used to oscillate the grain at a frequency of 25 Hz for a duration of 1 minute. Milled samples were sifted through a 1 mm sieve and stored in sealed plastic bags at room temperature prior to analysis. Nitrogen was determined in a CHN analyser (2400 series II, Perkin Elmer, USA) and protein content was calculated by applying a multiplication factor of 5.7 as described by Pogna et al. (2014). Total starch content was determined using Megazyme kits K-TSTA-50A / K-TSTA-100A (Megazyme, Ireland), after pre-treatment by ethanol extraction to separate soluble sugars from the starch. Approximately 100 mg of milled sample was added to 3 mL of 80 % ethanol and incubated at 60 °C in a water bath for 1 h. The samples were centrifuged and the supernatant removed. The residue plug was resuspended in ethanol and centrifuged a second time before storage and analysis.

Dough rheology

Approximately 10 g grain from each field replicate were combined and ground in a hammer mill (Laboratory Mill 3100, Perten Instruments, Australia) fitted with 0.8 mm screen. Meal weight was corrected to an 11 % moisture basis (mb) and water addition (%) for perennial samples determined using the equation 38.6 + (11 %mb protein content of sample × 1.5), while annual wheat and triticale samples received 5 % more water.

Data handling and statistics

The data collected from each parameter was analysed using multifactor ANOVA in SAS version 9.4 to test whether significant differences were observed between genotypes, experimental site and their interaction. The data collected as triplicate technical replicates were averaged. Plot was used as the block term in the analysis model. The predicted means were calculated and compared pairwise with adjustment to P values using Tukey’s method. Slice tests were calculated for interactions per site and genotype. In each slice test, the pairwise tests were calculated and adjusted to the P values using Tukey’s method. A confidence interval of 95 % was used in all analyses.

Results and discussion

Grain morphology

Significant differences in grain morphology and quality parameters were observed between the grain from different genotypes grown at the various locations (Table 1). For example, grain TKW ranged from 17.1 g to 38.6 g across genotypes in the 4 experimental sites. Wheat and triticale typically had significantly higher mean TKW than perennials. Overall, the experimental sites from 2018 presented significantly higher mean values for grain weight compared to the experimental sites from 2019. Grain length ranged from 6.92 mm to 6.31 mm, with grain from 2018 having significantly greater lengths than grain grown in 2019. DV width varied significantly between the different genotypes. Grain from annual genotypes were significantly wider than all perennial wheat genotypes. Also, significantly greater width values were observed in grain grown in 2018 compared to the 2019 season.

Our results indicate genetics and growing conditions exert a major influence on grain morphology characteristics. Annual wheat varieties have been selectively bred to be relatively spherical (shorter length and greater width) to provide better milling yield (Gegas et al., 2010) and perennials in this study lacked these characteristics and likely have a lower milling yield. If grains from perennial varieties are to be used for flour production, there would be some value in selecting morphology traits in future that maximise flour yield.

Grain colour
Some variation in grain colour was observed between the various perennial genotypes (Table 1). Some notable examples include perennial line 20238 which was characterised as significantly less yellow than all other genotypes. Perennial 251b was most similar to annual wheat variety, Wedgetail, in both grain brightness and yellowness. Depending on application, greater kernel pigmentation may be a positive attribute given the association with beneficial phytonutrients such as carotenoids and polyphenols (Martinek et al., 2014). However, for perennial grains to be included as flour components in food products, endosperm colour closer to typical wheat cultivars may be preferred. Hence, there needs to be a focus on selecting varieties based on intended end use.

Table 1. Variance analysis for functional properties of grains under genotype (G), experiment (E) and their interaction (G× E)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Genotype (G)</th>
<th>Experiment (E)</th>
<th>G × E</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External morphology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain length</td>
<td>&lt;.0001*</td>
<td>0.0043*</td>
<td>0.0932</td>
</tr>
<tr>
<td>Grain weight</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td><strong>Grain width</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front to Back</td>
<td>&lt;.0001*</td>
<td>0.0213*</td>
<td>0.0469*</td>
</tr>
<tr>
<td>Left to Right</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
<td>0.0808</td>
</tr>
<tr>
<td><strong>Grain colour</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>&lt;.0001*</td>
<td>0.0563</td>
<td>0.0029*</td>
</tr>
<tr>
<td>a*</td>
<td>&lt;.0001*</td>
<td>0.0020*</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>b*</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
<td>0.0006*</td>
</tr>
<tr>
<td><strong>Chemical composition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein content</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Starch content</td>
<td>0.0035*</td>
<td>&lt;.0001*</td>
<td>0.0266*</td>
</tr>
</tbody>
</table>

*Grain starch content*

The mean grain total starch varied greatly across all samples by year (Figure 1). On average, starch content of grain from 2018 sites were significantly higher than grain grown in 2019 due to less favourable grain filling conditions. There was no significant difference between annual and perennial genotypes. More information on perennial wheat starch functionality, such as pasting properties, amyllose/amyllopectin ratio, and resistant starch content, is required to better understand potential end uses.
Figure 1. The effect of site on protein content, grain weight and starch content

Figure 2. The effect of genotype on protein content, grain weight and starch content
**Protein content**

Average protein content of grain from the various perennial genotypes ranged widely and were typically significantly higher than annual wheat and triticale (Figure 2) as seen in similar studies (Pogna et al., 2014; Murphy et al., 2009). The higher protein levels observed compared to modern annual genotypes is likely to be due to the dilution effect caused by the higher yields achieved by commercial annual wheat varieties. Protein content is not necessarily an accurate predictor of bread making quality alone, as the ability to produce high quality bread is influenced by both protein content and composition. To establish an understanding of the potential bread-making quality of the various genotypes a more detailed study of protein composition is required.

**Dough rheology**

Some preliminary rheological investigations were performed within this study using a 10 g mixograph (National Manufacturing, USA). While most of the genotypes displayed relatively poor rheological properties, it was found that line 235a displayed mixing characteristics similar to the annual wheat variety Wedgetail (data not shown). The results from this study may not represent a true reflection of the rheological properties of perennial wheat as the methods used to measure dough quality have been optimised for modern annual wheat varieties. Work may be needed to design quality measurements that are more appropriate for these novel genotypes. For example, the water requirement for the perennial wheat was much lower compared to the annual genotypes. Also, due to the small amount of sample available, analyses were conducted using wholemeal flour which does not provide optimal results. The true dough making performance of these perennial lines would be better understood by utilizing the milled white flour fraction.

**Conclusion**

While the quality and functionality of the grain samples harvested from perennial wheat genotypes was generally poor compared to the annual wheat variety control, they did possess some useful quality characteristics which could see an application for them in the food ingredient market. These applications could be in products that require high protein levels to achieve protein claims, or as ingredients providing health benefits. Perennial grains have the added advantage of being produced in what consumers may view as a more sustainable way, hence be willing to pay a premium for products made with these grains. Commercial viability of perennial genotypes will almost certainly depend on their commanding premium prices.

**References**


Market failure in the Australian pasture seed supply chain and implications for perennial grains

Richard C. Hayes

NSW Department of Primary Industries, Pine Gully Rd, Wagga Wagga, NSW 2650, email: richard.hayes@dpi.nsw.gov.au

Abstract

Intellectual property in plant genetic resources is generally covered in Australia by Plant Breeder’s Rights (PBR). Cultivars can be registered under PBR if they are demonstrated to be new, distinct, uniform and stable. A PBR-registered cultivar affords the owner a period of exclusive market control and access to end-point royalties and/or commissions from the sale of seed, which for most herbaceous species is 20 years. This regulatory framework has only existed in Australia for around 30 years. Plant breeding in agriculture prior to 2000 was predominantly the domain of public breeding programs in Government agencies. Market failure in the seed supply chain exists when consumers do not have reasonable access to the best genetic material available. Drawn into question is the appropriateness of the modern centralised approach to plant breeding and its capacity to deliver genetic progress relevant to localised environments. The lack of any requirement for new varieties to be agronomically superior under PBR undoubtedly contributes to a lack of genetic progress in new cultivars. A recent review of laws governing intellectual property in Australia conducted by the Australian Productivity Commission identified some deficiencies in the PBR framework and flagged the large potential for market failure in the Australian seed supply chain. Market failure currently exists for a range of forage species for which there is now little investment in new cultivar development. Varieties for which there is a small market size and which require infrequent planting are at particular risk. The experience in the forage seed industry serves as a caution that ready access to novel perennial grain material cannot be taken for granted as the weak market forces may not assure the supply of seed, given they are perennial and likely to be niche in the first instance. It is uncertain whether the end-point royalties that would be paid on PBR-registered perennial grain cultivars upon the sale of grain, in contrast to forage species, is sufficient to mitigate this risk. Perennial crop development may therefore require a seed supply chain where seed growers are more closely connected with their markets than is presently the case in the forage seed industry.

Key words: End-point royalty, plant breeding, genetic improvement, pasture

Introduction

Plant Breeder’s Rights (PBR) is the primary mechanism for protecting intellectual property (IP) in new plant varieties in Australia. It is a relatively new regulatory framework following the passing of the Plant Variety Rights Act 1987 and subsequently, Plant Breeder’s Rights Act 1994. Cultivars can be registered under PBR if they are demonstrated to be new, distinct, uniform and stable. There is no requirement for any new cultivar to be in any way superior to old cultivars, so long as it meets the requirements of PBR. A PBR-registered cultivar affords the owner a period of exclusive market
control and access to end-point royalties and commissions from the sale of seed which, for most herbaceous species, is 20 years.

The potential for market failure is perhaps greater in plant development than in most other forms of IP (Productivity Commission 2016). In effect, once a new crop or variety has been sold for the first time, the buyer generally has the capacity to propagate the material, through seed or cuttings, thereby circumventing the ‘market’. It is perhaps for this reason that the development of plant cultivars was traditionally undertaken within the public sector with new varieties being made freely available (Sanderson and Adams 2008). The potential for market failure is even greater in niche species where market size is limited, in species less suited to end-point royalties and those requiring less frequent planting, such as perennial and self-regenerating annual forages (Productivity Commission 2016). Although increased opportunity exists to recover end-point royalties in perennial grains compared to forages, the small initial market size together with infrequent planting combine to present a substantial risk of market failure in this emerging crop. This paper examines specific examples from the forage seed market to inform likely outcomes for emerging perennial grain crops.

New species to agriculture

When considering obstacles to seed supply of novel perennial grains, it is instructive to look to precedents of other species new to agriculture. Australia boasts many such examples, particularly annual self-regenerating forage legumes (Nichols et al., 2007). Despite the annual growth habit, the self-regenerating annual can be an important part of perennial farming systems, requiring infrequent re-seeding. All of the herbaceous legumes used in Australian agriculture are exotic and some of the species are not even sown for agriculture in their country of origin, although they might be grazed as part of the local flora in native grasslands (Nichols et al., 2012).

In considering the occurrence of market failure in the seed supply chain, the Productivity Commission (2016) deemed that cultivars released post-2010 were likely to be products of the new, PBR-based market conditions. Cultivars released before that time were considered more likely a legacy of the old public breeding programs. This is because of the long (~15 years) lead-times in developing new pasture cultivars and the quantum of material still in the production pipeline as a result of the public programs. It is useful to assess the rate of release of cultivars of species ‘new’ to agriculture in both the pre- and post-2010 eras to assess the likelihood of the private sector investing in such species into the future. Cultivars of only 4 new species have been developed in the decade since 2010, compared to 28 cultivars in the two decades prior (Table 1). In at least three of those four examples there was still a substantial contribution from public agencies to develop the new cultivars. Clearly, there is less emphasis now on the development of new species. Factors contributing to this undoubtedly include the large resources required to conduct ‘duty of care’ grazing experiments to demonstrate the suitability of new species to livestock, and reduced investment in extension by public agencies to provide management guidelines to farmers and consultants, all of which increases the investment risk for the private sector in new species development (P. Nichols pers. comm).
Table 1. The number of cultivars of new* forage legumes released in Australia pre- and post-2010. (Source: Oram 1990; Nichols et al., 2012; IP Australia 2021).

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>Number of cultivars released</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1990-2010</td>
</tr>
<tr>
<td>Biserrula pelecinus</td>
<td>Biserrula</td>
<td>2</td>
</tr>
<tr>
<td>Bituminaria bituminosa</td>
<td>Tedera</td>
<td>0</td>
</tr>
<tr>
<td>Dorycnium hirsutum</td>
<td>Hairy canary clover</td>
<td>0</td>
</tr>
<tr>
<td>Hedysarum coronarium</td>
<td>Sulla</td>
<td>4</td>
</tr>
<tr>
<td>Medicago orbicularis</td>
<td>Button medic</td>
<td>1</td>
</tr>
<tr>
<td>M. sphaerocarpos</td>
<td>Sphere medic</td>
<td>1</td>
</tr>
<tr>
<td>M. tornata × M. littoralis</td>
<td>Hybrid disc medic</td>
<td>1</td>
</tr>
<tr>
<td>M. truncatula × M. littoralis</td>
<td>Hybrid barrel medic</td>
<td>2</td>
</tr>
<tr>
<td>Melilotus albus</td>
<td>White melilot</td>
<td>2</td>
</tr>
<tr>
<td>Melilotus siculus</td>
<td>Messina</td>
<td>0</td>
</tr>
<tr>
<td>O. sativus × O. compressus</td>
<td>Hybrid serradella</td>
<td>1</td>
</tr>
<tr>
<td>Trifolium alexandrinum</td>
<td>Berseem clover</td>
<td>2</td>
</tr>
<tr>
<td>T. dasyurum</td>
<td>Eastern star clover</td>
<td>1</td>
</tr>
<tr>
<td>T. glanduliferum</td>
<td>Gland clover</td>
<td>1</td>
</tr>
<tr>
<td>T. incarnatum</td>
<td>Crimson clover</td>
<td>3</td>
</tr>
<tr>
<td>T. spumosum</td>
<td>Bladder clover</td>
<td>1</td>
</tr>
<tr>
<td>T. tumens</td>
<td>Talish clover</td>
<td>1</td>
</tr>
<tr>
<td>T. vesiculosum</td>
<td>Arrowleaf clover</td>
<td>4</td>
</tr>
<tr>
<td>Trigonella balansae</td>
<td>Trigonella</td>
<td>1</td>
</tr>
<tr>
<td>T. repens × T. ambiguus</td>
<td>Hybrid white clover</td>
<td>0</td>
</tr>
</tbody>
</table>

*Species of which no cultivars existed in Australia prior to 1990

Rare forage species

Market failure also exists with some older forage species in Australia for which seed is now almost impossible to acquire, even just for trialling. Researchers at the NSW Department of Primary Industries have undertaken a range of forage evaluation experiments over the past two decades and have first-hand experience in the challenges posed in accessing some material. Two such examples include the perennial legume sainfoin (*Onobrychis vicifolia*) cv. Othello and mountain rye (*Secale montanum*) cv. Black Mountain, both of which have proven very difficult to source for small-plot testing (M. Newell pers. comm). In the case of sainfoin, this is exacerbated by the unavailability of suitable rhizobia for symbiotic N-fixation (J. Rigg pers. comm), without which any planting would seem almost doomed to failure anyway. Several factors are in common with these two cultivars:

1. Both underwent extensive testing and development in Australia.
2. Both are the only locally developed cultivars of their respective species.

Prospects for reviving these species as forages would appear remote due to several factors:

a) There is presently no demand for these species in Australia meaning that any market would need to be developed from the beginning.
b) These old cultivars pre-date PBR which means that no player in the seed supply chain enjoys a market advantage. Therefore, any player that invested to develop a market to increase demand among growers risks being under-cut by competitors in the supply chain.

c) Both have undergone a reasonable amount of development for Australian environments, dating back to the days when plant development was in the realm of public agencies. Significant additional investment would be required for genetic progress to achieve new cultivars of these species that are superior to the old public cultivars.

However, both species are also being considered as candidate perennial grains. This would be a completely novel market and likely require the development of new cultivars with traits considered less important in a forage, such as grain quality. In this circumstance it is possible to imagine that players in the supply chain could justify investing in developing a new market with little fear of being under-cut by a competitor pedalling the old forage cultivars.

**Achieving genuine genetic gain**

The development of new cultivars is not the only metric by which market failure might be gauged. Arguably, market failure may also be a lack of genetic gain. The Productivity Commission (2016) acknowledges that PBR has fallen short on delivering genuine genetic improvement:

> "While PBR have stimulated greater investment and private sector participation in plant breeding, it is less clear that they have delivered more and ‘better’ varieties..."

There are likely multiple contributing factors to this outcome. First is the lack of any requirement by the regulatory framework to demonstrate ‘superiority’ in new cultivars. Secondly, particularly for species that had previously undergone significant development by the public sector, further genetic improvement would likely take substantial investment in time and resources. Why would a player in the seed supply chain make such an investment when there is no requirement to do so?

Moreover, there is evidence that livestock breeding has traditionally ignored natural selection in the development of quantitative genetics (Beilharz 2000). This undoubtedly also applies to plant breeding. Natural selection is an ongoing process of plants adapting to their environment. In perennial systems, the environment is dynamic, comprising stark variation in seasonal conditions with time, coupled with variability in grazing and other management, and the various interactions that these driving forces have on factors such as soil fertility, pest/disease burden, competition and plant succession. Two strategies to help incorporate natural selection into plant genetic improvement programs are:

a) Regional plant breeding, or comprehensive evaluation across multiple regionally relevant environments.

b) Localised seed production using regionally relevant agronomic management to avoid genetic drift.

The modern seed supply chain has less capacity to deliver cultivars that are genuinely regionally adapted compared to the pre-2000 era. Perhaps the annual pasture legume, subterranean clover (*Trifolium subterraneum*), provides an instructive case-study to illustrate this point. The early 1990’s saw the concurrent release of three new late-maturing subterranean clover cultivars, cvv. Goulburn, Leura and Denmark. This was at a time when multiple public agencies were working collaboratively to trial breeding lines across many contrasting environments of southern Australia. In NSW alone, the late maturing cohort was tested at no less than 16 different sites from Armidale to Bega, examining productivity and seed production traits (B. Dear pers. comm). At the end of the testing period, three different State agencies each sponsored a different line to progress to commercialisation; NSW
preferred the line that became known as cv. Goulburn, Victoria favoured cv. Leura and Western Australia favoured cv. Denmark. Although from the same cohort of material, the agronomic traits of the three cultivars differed. For example, cv. Leura was a later maturing line than the other two; cv. Goulburn had a higher level of hard seed. All three varieties became successful and are still commercially available today, despite the expiry of PBR. By contrast, in the modern era, new cultivars are tested at a fraction the number of sites providing a much less robust approximation of the likely performance of new lines under the myriad environmental conditions to which they will be exposed on commercial farms. There is no longer the State-based advocacy for lines that are better adapted to priority target environments on a regional basis. Also, seed production is now much more specialised with fewer farmers producing pasture seed (Moss et al., 2021) and many regions across Australia now having no pasture seed producers.

Emerging perennial crops

The primary driving force behind the development of perennial crops globally is for a less ecologically intrusive approach to crop production. The damage that intensive cultivation of annual crops does to soil health and ecosystems has been well documented. Perceived benefits of a perennial crop include increased diversity associated with polycultures (Ryan et al., 2018); improved soil health attributable to reduced intensity of disturbance and soil organic matter accrual (Crews et al., 2016); and reduced greenhouse gas emissions associated with lower inputs of nitrogen (N) fertiliser (Crews and Peoples 2004), fewer carbon (C) emissions (Crews et al., 2016), and potentially, reduced methane emissions from livestock grazing a polyculture (Muir et al., 2020). It seems likely that end-users of perennial grains will look to take advantage of such factors in the marketing of products in order to capture a somewhat altruistic consumer that is prepared to pay more for a product in the knowledge that these other benefits are realised. However, these benefits are only perceived and there is no guarantee that management practices required to achieve these outcomes would necessarily be applied in the cultivation of a perennial crop. For example, there is nothing to stop a grower planting a perennial crop in a monoculture, or fertilising it with synthetic N fertiliser, or keeping the crop for only one year before removing it. All of these practices would potentially undermine the perceived benefits of a perennial crop and may jeopardise the uptake of the technology. It could therefore be reasoned that a contributing factor to potential market failure would be the agronomic practice used to grow the crop. No such risk exists with most other grain crops and forages.

Alternative supply chain models

Despite concerns around market failure articulated here, precedents do exist in Australia for the successful introduction of, what were initially, niche crops, notably rice (Oryza sativa) and cotton (Gossypium hirsutum). The supply chain in the rice industry is a cooperative model. Initially a grower-based association, the cooperative shifted its focus to vertical integration by investing in infrastructure to mill and market their own rice (RGA 2021). This cooperative had a very strong regional focus reflecting the production area, based around the Murrumbidgee Irrigation Area of the Riverina region of NSW. A total of 15 cultivars of rice have been registered for PBR in the last 30 years. By contrast, cotton, including the seed supply chain, is a self-contained industry in Australia which exists across a much wider geographic area than rice. No fewer than 110 cultivars of cotton have been registered for PBR, with all but a few registered either to the CSIRO or to Monsanto (IP Australia, 2021). Some traits in cotton, such as genetically-modified (GM) insect control and/or herbicide tolerance traits, are licensed which means growers have to purchase both seed and a license in order to grow those cultivars and utilise the specific traits. Currently >99% of cotton seed grown in Australia has one or more GM-trait (M. Peoples pers. comm). Other ‘native’ (non-GM) traits, such as improved water-use efficiency, fibre quality or disease resistance traits, do not require a license but are embedded with the seed, upon which growers pay a small royalty fee. There is only one distributor
of cotton seed in Australia, Cotton Seed Distributors (CSD), which is part-owned by cotton growers and breeding is undertaken by Cotton Seed Australia, a joint-venture between CSD and CSIRO.

Conclusion

The risk of market failure in the seed supply chain of novel perennial grains seems high, attributable to the niche nature of the crop limiting market size, infrequent sowing reducing commissions on seed sales, and potentially, lower yields limiting end-point royalties. All of those factors serve as a disincentive to the private sector looking for commercial opportunities in the seed market. Developing regionally adapted material from a centralised breeding program will be as much a challenge in perennial crops as it is in the suite of forage species presently available. Together, the PBR regime and the modern free market favour a ‘single trait’ selection process. Firstly, only one trait is required to satisfy the PBR requirement that a breeding line is distinct; secondly, it is an expensive process to improve multiple traits. However, a single trait may not automatically constitute a ‘better’ cultivar, especially where complex factors such as ‘persistence’ are important, drawing into question whether genuine genetic gain can be anticipated under the present regulatory framework. Combined, these factors suggest that seed supply of a novel perennial crop cannot be taken for granted and that it seems unlikely that market forces alone could be expected to reliably deliver seed to sustain a new market. More likely, a more integrated approach will be required which fosters closer relationships along the seed supply chain than is presently experienced in the forage seed industry. This seems especially relevant to the fledgeling perennial grains market where agronomic practices used to grow the crop may be as important as delivering the grain itself. Some collaborative supply models exist in Australia, such as the co-operative model used in the rice industry or the license model used in cotton. However, further work is required, in consultation with the end users, to determine whether either of these models would be suited or could be adapted to the emerging perennial grains industry.

Acknowledgements

I gratefully acknowledge the helpful comments from Dr Phil Nichols (University of Western Australia), Matthew Newell (NSW DPI), Mark Evans (NSW DPI) and Dr Mark Peoples (formerly CSIRO) on aspects of this paper. Any remaining errors in fact or interpretation remain mine alone.

References


Development and commercialisation of specialty grains: Lessons from gluten-free barley and high fibre wheat and barley

Philip Larkin\textsuperscript{1} and Crispin Howitt\textsuperscript{2}

\textsuperscript{1} Honorary Research Fellow, CSIRO Agriculture & Food, Canberra, Australia
\textsuperscript{2} Group Leader, New Markets, CSIRO Agriculture & Food, Canberra, Australia

Abstract

We describe four examples of specialty grains developed in CSIRO and reflect on issues and challenges along the path to bringing them to market and impact. Each of the four examples were developed with a human health objective: High fibre barley, BARLEYmax; High fibre wheat, HealthSense; Gluten-free malting barley, Kebari; and Gluten-free food barley. One lesson in common is that the research objective needs to be soundly based in order to convince the research institution to carry many years of investment, because grain and food companies rarely have sufficient interest to invest early in breeding specialty grains. Early consultation with experts in digestive health and coeliac disease was critical in shaping the breeding objectives for high fibre cereals and gluten-free barley. It is important also to test the validity of the “solution” through the eyes of grain and food industry sectors. In each of our cases investment in research was required for over a decade before achieving proof-of-concept.

If possible, it is important to capture and protect valuable intellectual property at the point of proof-of-concept. Investors require some degree of exclusive access which IP allows. In addition, achieving the intended impact requires many other players along the value chain who will participate only if they can be compensated for extra costs, which might include lower yield, segregation costs, marketing resistance, and more expensive final product. New agricultural products have to enable profit sharing along the entire supply chain; there has to be a reason for each party to participate in a specialty product. This was especially challenging for gluten-free barley whose value proposition required strict identity preservation. The yields were lower and identity preservation was expensive in the field, during transport and storage.

For sustainability the proof-of-concept product requires ongoing breeding for yield, disease resistance and adaptation, especially to enter new market zones. Spin-out companies or licensees chasing early business and profit, may have few resources and give low priority for on-going breeding. The research institute may also be reluctant to support further breeding making this period risky for the long-term viability of the product. It is the commercial partner who will determine when you have a minimal viable product (MVP) that can be tested in the market while improvements continue.

CSIRO launched BARLEYmax as a spin-out company, now called The Healthy Grain with some investment by the Grains Research and Development Corporation (GRDC) and venture capital. In this case the researchers remained consultants with on-going research but were not founders in the company. Examples of its success in Australia and Japan will be given. For high fibre wheat (HealthSense), CSIRO formed a joint venture, called Arista, with a major grain company, Limagrain. Arista is benefiting from the global connections of Limagrain with first products in North America. In the case of malting Kebari, CSIRO has to-date opted to organise grain supply and seek to license the use of the grain or malt to brewers, with the first product released in Germany. Difficulties with this
model will be discussed. The food version of Kebari has been exclusively licensed to *The Healthy Grain*.

Careful early consideration needs to be given to the competitive environment. For example it was thought the familiar barley malt taste with Kebari would be preferred to gluten-free beers made from sorghum or rice. However the development of Clarax enzyme technology, to digest the hordeins, had not been anticipated, and represents serious competition, requiring minimal modifications to the brewing process and no need for identity preservation of grain.

It is wise to give careful thought up-front to the marketability of the intended product. Technical trials may be positive, but food companies require a marketing angle that will allow market penetration despite the inevitable premium price. Food claim regulations are strict and vary in different jurisdictions, e.g. gluten-free labelling, environmental credentials, and permissible health claims.

**Key words:** BARLEYmax, HealthSense, Kebari, resistant starch

**Introduction**

Our Group in CSIRO has produced four health-promoting specialty cereal grains which have been, and are being, taken to market utilising a variety of mechanisms, spin-out companies or partnership structures. The rates and depth of uptake vary not only with the nature of the value-added trait but also the choices regarding pathways to market. Some reflection on these examples may prove instructive for future speciality grains including those with differentiating sustainability credentials such as perennial crops.

In the agriculture and food industries the research institution generally has to carry many years of investment in a new speciality crop, in Australia hopefully with the support of the general industry and government R&D corporations, in our case the Grains Research and Development Corporation (GRDC). Only persuasive concepts will survive the long-term up-front investment needed. Of course, agricultural R&D corporations investing farm levies will generally be looking for outcomes that benefit large segments of the agricultural community; the case for specialty grains faces some extra difficulties by that criteria. Our experience is that food companies generally like to deal with bulk commodity ingredients, and very rarely will have an appetite for early investment risk with specialty grains.

**High-amylose barley (BARLEYmax)**

The health concept behind BARLEYmax emerged from pioneering research in what was CSIRO Human Health from the 1990s (Topping 1991), by which it was established that forms of starch called resistant starch, resisted digestion in the small intestine and became available for fermentation in the bowel, producing short chain fatty acids (SCFA), notably butyrate. Established health benefits included: low glycemic index and load; reduced serum cholesterol and LDL-cholesterol; SCFA acting as a preferred energy source for colonocytes; strengthened gut mucosal barrier and immunity; suppression of pathogenic gut bacteria; reduction of inflammation-mediated ulcerative colitis; reduced incidence of bowel cancer (reviews Fung *et al.* 2012; Topping *et al.* 2010). Informed by this work we sought means to achieve higher content of resistant starch in barley. One form of resistant starch could be achieved by increasing the relative proportion of unbranched starch (amylose) to highly branched amylpectin, resulting in more compact starch granules that resisted penetration of starch degrading enzymes in the intestine, but being available for fermentation in the bowel. Mutant populations of barley were screened to find one with high amylose content, called Himalaya 292 (Bird *et al.* 2004).
Breeding was undertaken to remove unwanted mutations and to improve the agronomy and the resulting barley was branded as BARLEYmax.

The prospects to commercialise a speciality grain usually depend on being able to offer degrees of exclusivity to any company taking on the risk and opportunity to find a path to market. That in turn requires securing intellectual property. In the case of BARLEYmax that was achieved by understanding the gene that had been mutated (Morell et al. 2003) and defining the product through patents in the major global jurisdictions envisaged for products.

Studies to substantiate health claims were also crucial and expensive. Specialty grains inevitably involve increased cost of production, often because of lower yield and always because of the requirements for identity preservation along the supply chain. Consequently, food products will demand a premium which will demand valid health claims acceptable to the food regulators.

Some larger food companies tested BARLEYmax products successfully and liked the idea of making high fibre claims. However, they opted for alternative cheaper processing solutions, such as adding inulin. The new global trend to so-called clean labels, requiring fewer additives, may swing the benefit-cost determination back toward ingredients like BARLEYmax.

BARLEYmax was licensed to a spin-out joint venture The Healthy Grain company (THG), which sublicensed the use of the grain and the brand to a few smaller food companies to produce breakfast cereals, muesli bars and wraps selling through major supermarket chains. One early lesson through this experience was that once a licence has been given the research group has little or no control over the final products. For example, there was some criticism that early muesli bars had too much added sugar, diluting some of the intended health benefits. Since 2008 THG has attracted venture capital and more recently major investment by the Japanese company Teijin. The latter in particular has diluted CSIRO’s ownership even further but has accelerated penetration of a surprising variety of products into the Japanese market. Major bread brands have now launched BARLEYmax products, notably in Australia Goodman Fielder’s Helga’s Digestive Wellbeing Range and in New Zealand Vogel’s Digestive Wellbeing Range.

Early versions of BARLEYmax carried a substantial yield penalty (>20%) when grown in Australian environments. Because of the need for identity preservation, it has not been released as a new variety but is produced under closed loop contracts. It became important to recognise that a viable supply chain for a specialty grain such as BARLEYmax needed all parties along the supply chain to be rewarded. That adds to the premium price the grain must demand which in turn reinforces the importance of the health claims and the ability to offer degrees of exclusivity to the participants. The low initial yields had to be addressed and versions needed to be bred suited to new market jurisdictions such as the UK, Europe and North America. While THG was small it was difficult to fund that breeding and CSIRO was increasingly reluctant to continue investing into a product which it viewed as already having been passed on to a commercial partner with the science already completed. Capital raising by THG is allowing that breeding to be undertaken.

**High-amylose wheat (HealthSense in North America)**

The success with BARLEYmax inspired efforts to develop a similar high fibre, high resistant starch wheat. Technically this was much more difficult because of the wheat’s hexaploid genetic structure; mutations in any one of the three genomes would be masked by the other two genomes and therefore would usually be invisible phenotypically. Transgenic gene silencing across the genomes was used to confirm the appropriate genes in the starch biosynthetic pathway that needed to be mutated (Regina et al. 2006). Subsequently mutations were found in these genes in each of the three genomes and assembled into the one line. The accumulation of amylose proved even higher than in the experimental transgenic line (Regina et al. 2015). The predicted health benefits of high amylose wheat are similar to those described above for BARLEYmax, and have been substantiated in human
trials (Newberry et al. 2018; Belobrajdic et al. 2019). The greater use of wheat as a food promises greater impact.

In the case of High Amylose Wheat (HAW) a joint venture was formed called Arista Cereal Technologies, involving a major European seed company, Limagrain. The decision was made to commercialise first in North America, and a licence was issued to Bay State Milling, a company focussed on healthful food ingredients. Arista and Bay State Milling undertake ongoing breeding for North America and production of grain or flour for sale to food companies. In North America HAW is marketed as HealthSense or its flour for home bakers as Flourish. Supply deals have been negotiated with major food manufacturers.

Major food companies in particular are usually reluctant to invest in the development of a speciality grain even when the development phase is successful. Their market dominance means that they view new products, even from themselves, as competing against their own established products rather than expanding their market share further. If you wish to commercialise to a food company directly, you are more likely to attract the attention and investment of a second or third tier company wanting to invade market share through innovation.

One of the lessons from these examples is that the lead scientists need to be involved in the early years of transition to commercialisation. This may entail being funded by the commercial partner for new phases of product improvement. However, one of the dangers is that a spin-out company will be so cash-strapped and focussed on launching the minimal viable product (MVP), that the need for improvement is ignored. The commercial partners determine when you have a MVP that can be tested in the market while improvements continue; the inventing scientists may be uncomfortable about how early that decision is made. At the least, one of the researchers should be on the technical advisory board to ensure communication of the essential technical knowledge, including the deficiencies that need to be addressed, such as poor yield, disease susceptibility, quality fault, or poor adaptability for a major target environment.

Limagrain has power and global reach through its subsidiaries, enabling Arista to organise ongoing breeding of HAW for new target growing and marketing regions. This is an important and expensive contribution to the expansion and ongoing improvement of the product. The need for breeding never stands still.

**Hulled gluten-free barley (malting Kebari)**

Coeliac disease is an auto-immune condition triggered by exposure to even small amounts of gluten-containing cereals and affects approximately 1% of the population worldwide. Non-coeliac gluten sensitivity is reported by up to 10% of the population, is not well defined, and while usually self-diagnosed, impacts on sufferer’s purchasing habits. Avoiding gluten (hordein in barley) is the only option but comes with its own risks such as over-consumption of foods high in fat or sugar, and diets with insufficient fermentable fibre.

The CSIRO group needed to interact with experts in coeliac disease to understand how many of the proteins in barley would require elimination. There were many genes, but were clustered in a few locations, making deletions difficult but feasible. Hexaploid wheat had at least three times the number of genes compared to diploid barley; furthermore, the elimination of gluten from wheat would have destroyed its functionality for most of its uses such as bread. We undertook to breed a novel ultra-low gluten (ULG) barley variety with hordein content well below the levels recommended by the World Health Organisation as being safe for people with coeliac disease, currently 5ppm (Howitt et al., 2018). Three deletions or mutations were found eliminating different classes of hordeins. When combined by breeding the objective was achieved (Tanner et al., 2016), and following further breeding to increase seed size, the resulting grain was branded as Kebari. The original line, hereafter called malting Kebari, was in a hulled barley background suitable for malting and brewing. These
grains retain the husk (lemma and palea) when harvested and malted, which brewers use as part of the filtering process in separating solid particles from liquids as the wort is run off at the end of mashing.

One of the early considerations was the competitive environment. A gluten-free barley beer would have to compete with other gluten-free beers made from sorghum or rice. It was considered likely that the familiar barley malt taste would be unaffected by the absence of gluten (hordein) proteins, and that would achieve a competitive advantage. Trial brews in Australia confirmed that prediction and a major German brewer, Radeberger, undertook extensive trials and product development and launched a gluten-free barley beer in 2016 called Pionier. However, more competition has emerged for gluten-free brewing in the last few years, in the form of enzyme technology, called Brewers Clarax, used to digest the hordeins. This technology requires minimal modifications to the brewing process and eliminates the need for identity preservation of the barley malt and clean down of equipment. In Europe the use of enzymes disqualifies the product claiming conformity to the much-lauded 500-year old brewing tradition called the Reinheitsgebot. This is no impediment in the rest of the world.

A major challenge has been the variable food regulations around the world regarding the label “gluten-free”. In Europe it was clear that any product made from Kebari would have much less than 5ppm gluten and could be labelled gluten-free. In Australia the current regulations effectively rule out using that label for anything made from barley; the Kebari innovation was not anticipated or allowed for. While the regulator FSANZ is supportive of a change, it has chosen not to recommend a change to the legislation unless and until the coeliac societies of Australia and New Zealand support a change.

Identity preservation and avoidance of any contamination of gluten containing grains must be rigorously ensured from the field, through grain handling, malting and each step of transport and storage. This adds to the costs and the premium required. Contract growing and malting was the production choice. At this stage this has been handled by the lead scientists together with some resources from CSIRO’s Business Development team. Despite the early contract with Radeberger, it has proved difficult to devote sufficient time to develop further business opportunities. While other European brewers are showing interest to develop Kebari beers, it seems inevitable that some other commercialisation structure will be necessary.

Hull-less gluten-free barley (food Kebari)

Brewers strongly prefer malts made from hulled barley because the hull assists in the filtering process. By contrast, as a food ingredient, the indigestible hulls are problematic and therefore hulless (naked grain) varieties are strongly preferred. This is especially the case if wholegrain foods are intended to maximise the fibre and micronutrient content. While at the beginning of the research it seemed likely that the absence of hordein may not negatively affect the brewing process, it was less certain if it would substantially affect taste and texture for food applications. Having the malting Kebari allowed some food products to be successfully tested which removed some of the uncertainty and risk in proceeding to breed a hulless version, hereafter called food Kebari.

The processes and regulations associated with food differ substantially from those relevant to beer. As a consequence, we made the decision to separate the licensing of the malting and food Kebari lines. Food Kebari was licensed to The Healthy Grain company (THG) to capitalise on that well-developed partnership, THG’s practiced attention to identity preservation through the supply chain, and the contacts they had already formed nationally and internationally. The breeding and bulking up of food Kebari are just now at the stage of having sufficient quantities for food companies to undertake product testing. It is worth noting that new gluten-digesting enzymes, such as Clarex, cannot be effectively deployed for food products and therefore are not a competitive threat.

The segregation issue is even more acute for food Kebari because the amounts of barley protein will be much greater in a food product compared to beer. Tolerance would be very low for contamination from normal barley, rye or wheat at any point in the production and supply chain. For that reason and
with THG support, CSIRO has commissioned a major human study with coeliac disease patients to substantiate its safety as a food for those needing to avoid gluten. The COVID-19 pandemic has caused that trial to be halted just as it was getting underway.

Although we had chosen to separate the two versions of Kebari for commercialisation approaches, the wisdom of that decision may be challenged. A company may perceive marketing synergies and potential for both beer and food products yet hesitate with the need to negotiate separate licences for both the malting and food versions with different entities.

Earlier we suggested that second or third tier food companies are more likely to be interested in a speciality grain in order to invade market share of the segment leaders. Food Kebari may be the type of grain that challenges this generalisation since it may in fact expand the size of the market with the prospect of luring gluten avoiders back to some cereal-based foods or beverages.

**Conclusion**

Our experiences with these four examples are varied, making generalisations difficult. The preferred commercialisation model for a specialty grain will depend on many factors including: the strength of its health or sustainability claim; whether there are alternative grains making similar claims; whether other technologies can solve the problem; the strength of your competitive advantage and IP; the complexity of the regulations around making a claim; the depth of interest/concern in the target populations for the solution being offered; the appetite of the food industry to support ongoing product improvement and breeding.

Investment in a specialty grain is very unlikely from a food company that already has market dominance, and can only be expected from second- or third-tier companies when the value proposition is attractive to their prospect of growing their market share. Great scientific solutions don’t necessarily land with the impact they seem to deserve. Giving careful thought up-front to the marketability of the intended product may give it a shape that improves the prospect of impact. Even when all the technical hurdles have been cleared and food trials look positive, companies require a marketing angle allowing market penetration despite the inevitable premium price. Our experiences reinforce one generalisation, that success requires the lead scientists to step beyond their familiar networks to understand and interact with participants along the entire value chain, but then also to be prepared at some point to lose control of the baby nurtured for so long.

**References**


Certified Australian Sustainable Produce and growing a niche market for perennial grains

Miriam Neilson
Southern Cross Agricultural Exports, PO Box 29, Goodna, Queensland 4300 Australia, email: executive@southerncrossag.com.au

Abstract

Growing awareness of the impact on climate has increased at all levels. Consumer, Government and Business interest in food security and the role that agriculture and processing can play both positively or negatively on these climate issues, has led to further attention given to both the provenance and methods of food production. However, when it comes to bringing a novel and niche product to market, how can we ensure that the product supplied meets market expectations?

I will address key driving influences on emerging, environmentally friendly and climate-driven food markets, the market expectations across consumer segments, discuss potential in the food and beverage industries, and look at ways in which to initiate entry and establish growth in a competitive setting.

Since 2015 Southern Cross Agricultural Exports has been certifying Australian Sustainable Produce (ASP Certified) grains to be sold into premium markets. The information delivered here is largely derived from what has been learned through that process, both directly through our engagement with consumers and through our relationship with processors like Wholegrain Milling.

Introduction

“Imagine a world where the most the general population expects from big business is that it keeps its hands to itself—that it doesn’t take anything away from a community or the Earth—but rather it sustains. That’s the golden standard of sustainability. While sustainability is noble in its own right in that it’s a step up from exploitation and destruction, if the goal of being sustainable is simply to not have a negative impact on people and the planet, it’s time to raise the bar.” This quote from MJ Rowley (2021) a journalist writing about prioritising regeneration over sustainability, highlights the ever-increasing focus that consumers have on regeneration, the negative impacts that we as humans have had on the planet, the possibilities of reversing current problems and it begins to paint a picture of the possibilities for forward thinking agriculture and businesses to secure a growing niche in the Regenerative and Sustainable movements.

Market expectations across consumer segments

Conventional Agriculture’s unintended consequences are impacting on environmental, climate, ethical and social issues around the world, with recognition of this at all levels. Although there is no binding definition for the term “sustainable food”, labels have been on the rise for the last two decades.

An International Food and Management Review (IFAMA) study concluded in 2016, has shown five dimensions upon which successful sustainability-based differentiation and labelling strategies can be...
created: Innovation, Naturalness, Terroir, Ethics and Health (Sidali et al. 2016). The more attributes you can comply with, the better. Perennial grain is an innovative dual-purpose crop that has the potential to minimise environmental impact with less soil disturbance and have lower emissions due to its longevity.

**Climate change, emissions, and carbon capture**

Increased concern from the wider community regarding climate change is a leading marketing factor, but many consumers are still vague as to what actions can reverse it. Emissions reduction and increased carbon capture are well recognised pathways to positively impact climate issues.

**Table 1. The IFAMA breakdown of the five main Sustainability Factors (Sidali et al. 2016)**

<table>
<thead>
<tr>
<th>Sustainability Factor</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F 1 Ethical Attributes</strong></td>
<td>Ensuring animal welfare</td>
</tr>
<tr>
<td></td>
<td>Ensuring fair payment of producers</td>
</tr>
<tr>
<td></td>
<td>Ensuring good working and living conditions for producers</td>
</tr>
<tr>
<td></td>
<td>Environmentally friendly production</td>
</tr>
<tr>
<td></td>
<td>Environmentally friendly packaging</td>
</tr>
<tr>
<td></td>
<td>Reducing greenhouse gas emissions</td>
</tr>
<tr>
<td><strong>F 2 Naturalness</strong></td>
<td>Free from GMO</td>
</tr>
<tr>
<td></td>
<td>Free from chemical pesticides</td>
</tr>
<tr>
<td></td>
<td>Free from synthetic fertilizers</td>
</tr>
<tr>
<td></td>
<td>Free from artificial additives</td>
</tr>
<tr>
<td><strong>F 3 Health-related attributes</strong></td>
<td>Good taste</td>
</tr>
<tr>
<td></td>
<td>Safe</td>
</tr>
<tr>
<td></td>
<td>Fresh</td>
</tr>
<tr>
<td></td>
<td>Health benefits</td>
</tr>
<tr>
<td></td>
<td>High nutritional value</td>
</tr>
<tr>
<td><strong>F 4 Terroir</strong></td>
<td>Seasonal production</td>
</tr>
<tr>
<td></td>
<td>Local production</td>
</tr>
<tr>
<td><strong>F 5 Innovation</strong></td>
<td>Following current trends</td>
</tr>
<tr>
<td></td>
<td>Innovative</td>
</tr>
</tbody>
</table>
Proving claims

Hollow claims will not pacify the growing market; many consumers that you will be appealing to are “early adopters”, a more informed and discerning audience. Already consumers are raising concerns regarding “greenwashing” of the words sustainable and regenerative. Ensuring any claims are backed up with third party verified information is crucial.

Potential markets for perennial grains

Perennial grains have the benefit of being a recognisable product, and grain is very familiar to both the consumer and the processor, making it an easily adaptable innovation. Depending on the qualities of the grains we could see it move into all of the familiar grain products currently consumed. Breads, noodles, pasta, confectionary, beers and spirits. In the USA, an example of the innovation is the partnering of Patagonia, Hopworks and The Land Institute, to create a beer made specifically for Patagonia called “Long Root Beer”.

Consumer vs corporate, how to get the message out

Much of the current consumer analysis breaks the market sector down into four main areas of influence based on Myers Briggs type structure. Engagement with them needs to quickly capture the largest audience. Consumers are around 70% driven by emotion, feelings, and community. Engagement needs to focus on positive messages. Business to Business or corporate buying are dominated by Doers and Thinkers, so succinct, clear, exciting information is key in those areas.

The potential to capture attention and engagement with the way we frame the “story” or “branding” of our products is key. Understand who you are communicating with and build your story with separate messages that can appeal to the different buyer types. Delivery of the correct framing of information is almost as important as the information itself.

![Figure 1. Myers Briggs Personality Type breakdown. What are the drivers for your customer base? (White 2013).](image)
We are in the business of developing trust

In 2020, AgriFutures published a national survey of over 6000 people from a broad range of education backgrounds to gain a deeper understanding of Australian’s relationships with its rural industries (Voconiq, 2020). They explain:

“Community expectations around the way Australian rural industries operate is changing rapidly. Enabling Australia’s rural industries to understand these expectations as they evolve is important to ensuring rural industries engage productively with the community.”

Building trust with consumers to show that we as agricultural professionals understand our impact on the environment and the “Spirit” or story of our country is essential. Are we taking the necessary steps to ensure sustainable, profitable and socially responsible actions are being undertaken? It is a challenge when 90% of our population live in coastal areas. Over 40% don’t know anyone working in a rural industry and are reliant on receiving most of their information about rural industries via internet, television and social media.

![Diagram showing the relationship between environmental responsibility, responsiveness, industry products, trust, and acceptance.]

Figure 2. Engaging with the community to develop trust is key. (VoconiQ, 2020).

How?

One of my favourite quotes from Australian comedian and songwriter Tim Minchin is that one of the greatest education mistakes we have made is to separate the arts and sciences. What he is getting at is that communication, though factual, needs to be engaging. Dry data will only convert someone who can read and understand it. Let’s be factual, but understandable and interesting! No matter who you are communicating with, gain and maintain their interest.

We are privileged to be in on the ground floor

As invitees to this conference and first adopters of this innovation, we have the opportunity to learn so much to give us the power to craft a market that will grow into the future.
References


Appendix 1: Perennial artisan grains – user survey

Introduction

The ‘Perennial Artisan Grains’ project aims to characterise the milling and end use qualities of perennial cereal selections which have shown potential under Australian conditions. The project will link industry representatives with researchers in developing a viable perennial cereals industry in Australia. Funding for the project was received from AgriFutures Australia in collaboration with NSW Department of Primary Industries.

The use of perennial crops has the potential to diversify dryland cropping options, while improving the sustainability of agricultural systems and maintaining grain production. Perennial grains offer an opportunity to develop novel food products from grains possessing attributes not found in traditional cereal grains. Currently, there is no information on end use of perennial grains for human consumption. The selected perennial grains in this project have diverse pedigrees and may contain distinctive attributes with potential to develop products for milling, baking or brewing.

This user survey contributes to the development of perennial grains for food use. This is an important step as selected grains which perform well agronomically will be assessed for potential human consumption use. The data collected in this survey will identify key end use characteristics of the candidate grains. This information will be valuable in identifying potential markets for the future development of perennial grain crops in Australia.

General learnings from the survey will be shared at a workshop following the grain testing phase. A final report will be freely available through the grAiNZ and Agrifutures organisations. Information gathered from individual participants will remain confidential. If any of your responses are quoted in the final report, they will be presented without an identifier.
Background information

The following questions are to get an understanding of your business values and customer expectations. Please write your answers in the spaces provide below.

Business name:

What is your business type? Please circle your response.

- Mill
- Bakery
- Brewery
- Other:

How long have you been working in this industry? Please circle your response

- <5 years
- 5-10 years
- 10-20 years
- 20-30 years
- >30 years

List the main products you make.

- 
- 
- 
- 
- 
- 
- 

What is the outlet for your products? Please circle your response

- Shop front
- Online
- Farmers markets
- Supermarket
- Restaurant/Café
- Other (please specify)

Rank in terms of use the following grains in your business:

<table>
<thead>
<tr>
<th>Grain</th>
<th>Modern wheat</th>
<th>Heritage wheat</th>
<th>Cereal rye</th>
<th>Oats</th>
<th>Malt barley</th>
<th>Other (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What are the characteristics of the grain ranked first and why is it a preference?

Do you have previous experience with specialty grain types (e.g. spelt, korshan, buckwheat)? Please describe your experience.

What was your interest in participating in the Perennial Artisan Grains project?

The following statements refer to the values of consumers. Examine the statements and select a response which best reflects your customers’ preferences.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Disagree</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Don’t know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase products based on price</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefer wholemeal flour products to white flour products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select products based on health benefits (e.g. whole grains, increased vitamin and mineral content, low GI etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select products based on flavour.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The story of how the product is produced is important in their decision to purchase. (e.g. small scale, local produce, organic, the use of heritage wheat varieties for production over modern varieties)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concerned about the environmental footprint of food production (e.g. sustainably produced)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Perennial grain baking performance sheet

Entry:

Mill type: Please circle your response.

- Stone mill
- Roller mill

Product: Please circle your response.

- Tinned loaf
- Hearth loaf
- Enriched loaf, (e.g. brioche: added fat/ sugar)
- Flatbread, (e.g. pita)

The following attributes refer to the product selected above. Examine the attributes and mark a response which best represents your view.

<table>
<thead>
<tr>
<th></th>
<th>Very good</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loaf volume</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>External appearance</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Crumb texture</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Colour</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Flavour</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please comment on the following:

- Loaf colour
- Loaf flavour
- Loaf appearance

Overall performance of the product: Please circle your view

- Ready to market
- Needs more work
- Not worth pursuing further
Perennial grain brewing performance sheet

Entry:

Style: Please circle your response.

Lager Pale ale Dark ale Other (please list)

The following attributes refer to the product selected above. Examine the attributes and select a response which best view

<table>
<thead>
<tr>
<th></th>
<th>Very good</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aroma</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Taste</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Mouth feel</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Colour</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please comment on the following:

- Aroma
- Taste
- Mouth feel
- Colour

Overall performance of the product: Please circle your view.

Ready to market Needs more work Not worth pursuing further
Perennial grain processing performance sheet

Entry:

Product type: Please circle your response.

- Steamed and rolled
- Batch cooked, flaked and toasted
- Extruded

The following attributes refer to the product selected above. Examine the attributes and mark a response which best represents your view.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Very good</th>
<th>Good</th>
<th>Acceptable</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flake integrity</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Flake size</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Flake texture</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Colour</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Flavour</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Texture (extruded product)</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Please comment on the following:

- Flake integrity
- Flake size
- Flake texture
- Flavour
- Texture (extruded product)

Overall performance of the product: Please circle your view.

- Ready to market
- Needs more work
- Not worth pursuing further
Perennial grain performance survey

Briefly describe the process used to produce this product (e.g. 100% grain used, used as an additive to other flour, pre-sprouting, additives required etc.)

Was your product successful? Why or why not?

What qualities of the grain did you like?

What qualities need improving?

What alternative products could this grain be used for? (e.g. flat bread, crackers)

Would you like to continue working with this grain to further refine the product? Please circle your response.

Yes No Unsure

Do you see a market value for this grain? Why or why not?

If supply of this grain was unlimited could you estimate the volume of this grain you could use in your business?
Final comments

Would you be interested in future testing of new perennial grains?

Yes  No

If yes, please provide contact details:

Name:
Phone:
Email:

Any further comments about the project or using perennial grains?

Thank you for your participation. Your responses will provide the research team with valuable information in the future development of perennial grains. The research team appreciate your efforts.
Appendix 2: Perennial wheat sensory survey

1. Have you ever been on a bread taste testing panel?

Select your response

○ Yes. Done this before.  ○ No. ... what even is aroma

2. What is your gender? ________

3. What is your age group?

○ 30 or under  ○ 31 - 40  ○ 41 – 50  ○ 51 – 60  ○ Over 60

4. Rate the following for Sample A

<table>
<thead>
<tr>
<th></th>
<th>Dislike extremely</th>
<th>Dislike moderately</th>
<th>Neither like nor dislike</th>
<th>Like moderately</th>
<th>Like extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aroma</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Appearance</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Flavour</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Texture</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
</tbody>
</table>

Comments on Sample A:

5. Rate the following for Sample B

<table>
<thead>
<tr>
<th></th>
<th>Dislike extremely</th>
<th>Dislike moderately</th>
<th>Neither like nor dislike</th>
<th>Like moderately</th>
<th>Like extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aroma</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Appearance</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Flavour</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
<tr>
<td>Texture</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
<td>☆</td>
</tr>
</tbody>
</table>

Comments on Sample B:
6. Rate the following for Sample C

<table>
<thead>
<tr>
<th></th>
<th>Dislike extremely</th>
<th>Dislike moderately</th>
<th>Neither like nor dislike</th>
<th>Like moderately</th>
<th>Like extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aroma</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flavour</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments on Sample C:

7. Rate the following for Sample D

<table>
<thead>
<tr>
<th></th>
<th>Dislike extremely</th>
<th>Dislike moderately</th>
<th>Neither like nor dislike</th>
<th>Like moderately</th>
<th>Like extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aroma</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flavour</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td>☆☆☆☆☆☆☆☆☆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments on sample D:

8. If you had to buy a loaf of one of the samples, which would you choose?

Select your response

- Sample A
- Sample B
- Sample C
- Sample D
- None of the above