Breeding, Selection, and Quality of Partial Waxy Wheat: An Australian Perspective[1]

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ABSTRACT

Breeding new wheat varieties for Australian Noodle Wheat (ANW) and Australian Prime White Noodle (APWN) classes requires great understanding of the processing and end-product quality requirements suited for these wheat types. ANW includes unique varieties that have medium grain hardness, high flour-swelling volume and starch-pasting properties, medium water absorption and dough strength, and good, clean milling characteristics. Good color and color stability are also unique quality features of this wheat type. APWN is very similar to ANW in quality, but it is hard grained. These two types of wheat are often blended together into a "udon" blend. The two have unique, strict quality-testing requirements, with both requiring sensory assessment of udon noodles as the last quality check before classification. Innovations in ANW and APWN include further textural enhancement in breeding and selection of ANW and APWN wheat lines.

Australia produces about 25 million metric tonnes of wheat each year, which accounts for about 3–4% of global wheat production and 10–15% of global wheat exports. About 65–75% of Australia's total wheat production is exported each year, with Western Australia being the largest producing and exporting state (Fig. 1) (1,2). Wheat accounts for the majority of Australian grain production (Fig. 2). Depending on the location and annual growing conditions, wheat is sown during the April to June window. Most wheat varieties grown in Australia are spring wheat types (3).

The classification of a wheat variety into a marketing class comprising varieties displaying similar and/or complementary quality characteristics is a fundamental step in the production of marketable wheat classes. Other factors, such as physical and analytical standards, are also applied at grain receival, which, together with the inherent processing characteristics of the grain itself, combine to produce a recognizable and consistently performing product to take to the market.

Australian wheat varieties are classified into eight classes to meet distinct quality attributes for processors and end users. Wheat Quality Australia (WQA) is an independent nonprofit company jointly owned by the Grains Research and Development Corporation (GRDC) and Grain Trade Australia (GTA). WQA is responsible for the classification of new wheat varieties. The wheat classification process involves assessing the inherent quality characteristics of any new variety, with a focus on processing and end-use performance. The eight classes of Australia milling wheat are

- Australian Prime Hard (APH)
- Australian Hard (AH)
- Australian Prime White (APW)
- Australian Standard White (ASW)
- Australian Prime White Noodles (APWN)
- Australian Noodle Wheat (ANW)
- Australian Soft Wheat (ASFT)
- Australian Durum Wheat (AD)

Apart from AD and ASFT milling classes, the two arguably most unique classes of Australian milling wheat are ANW and APWN. Both are partial waxy types, and both are bred for the lucrative markets of Japan and South Korea and their white salted noodle quality requirements, with a very strict quality testing regime before classification, including udon sensory testing.

Quality Targets for ANW and APWN

ANW. ANW varieties must meet specific quality requirements for udon noodles, including starch quality, flour color, and color stability. ANW is used to make white salted noodles with a bright appearance, stable, creamy color, and slightly soft and elastic mouthfeel. ANW consists of white varieties that are medium grained with partially waxy starch, producing a high viscograph peak and high swelling volumes when the starch is gelatinized. ANW is primarily produced in Western Australia.

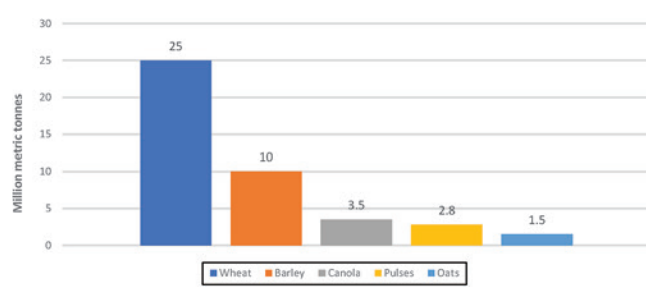

Fig. 1. Average grain production of Australia's major crops (5 year average). Data source: ABARES 2019 and AEGIC 2019.

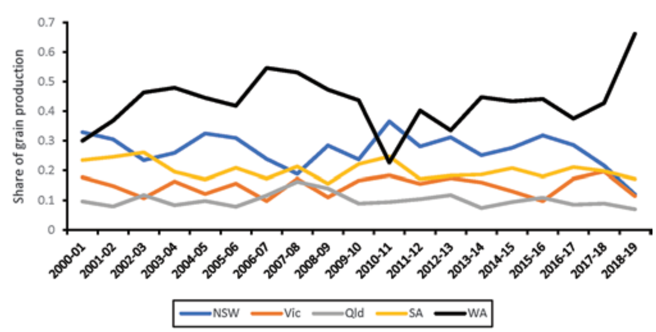

Fig. 2. State shares of Australian grain production since 2000–2001. NSW: New South Wales; Vic: Victoria; Qld: Queensland; SA = South Australia; WA: Western Australia.

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APWN. APWN is a premium hard grained specialty wheat with excellent starch and color properties. It is a relatively new class in the Australian system that was first introduced in the 2009–2010 season. APWN is well suited to blending with ANW for premium udon noodle applications. The quality characteristics of APWN are similar to those of ANW, except that APWN is hard grained. Quality characteristics include high flour extraction with low ash levels, white flour color, and bright and creamy noodle sheet color. APWN is also primarily produced in Western Australia (4,6,7). MixoLab profiles of the two "udon" classes are shown in Figure 3 and compared with "normal" starch hard wheat (AH).

As mentioned earlier both, ANW and APWN are specifically bred for the premium noodle markets of Japan and Korea. Typically, both markets obtain their noodle wheat as a blend of soft (ANW) and hard components (APWN and/or APW). Each market has unique specification requirements, which differ slightly due to the difference in applications of the wheat and slightly different products made in Japan and Korea. Also, there are slight consumer preference differences. Typically, Japanese consumers prefer slightly softer, more elastic (chewy), slightly creamier to slightly yellow noodles versus the firmer bite and whiter noodles preferred by Korean consumers. These preferences, together with seasonal variations in wheat quality, drive adjustments made to the blends of ANW and APWN as required. There are, of course, some varietal differences within each of the two classes, but the primary goal of the Australian classification process is to try and manage these differences (or minimize them by grouping similar varieties into similar wheat classes) (4). Seasonal impacts on grain quality in Australia are managed by the GTA receival standards (5).

Breeding of Partial Waxy Wheats

The establishment of a noodle class of wheat within the Australian classification system was the result of a recognition that there are particular characteristics within Australian wheat germplasm that are highly desirable from an end-user perspective (7). Further studies identified that the partial waxy characteristic was an important factor contributing to this suitability (8,9). However, there remain hurdles to continued improvement within this specialty wheat class. Aspects within a breeding program that can be manipulated to improve genetic gain include the size and variance of the population from which selections are made, the accuracy and intensity of those selections, and the time taken for those to be implemented. Manipulation of some of these levers for genetic gain are restricted when targeting noodle wheat development. Population variance is restricted due to a smaller gene pool, which is driven by tight quality constraints, and there are challenges in reducing cycle times due the requirements for sensory analysis to confirm ideal texture in end products, which requires significant resources, skill, and reasonable flour volumes. Despite the challenges, significant improvements in noodle wheats have been made and have been facilitated by improved knowledge of the impact of partially waxy genotypes on end-product performance and the deployment of associated technologies.

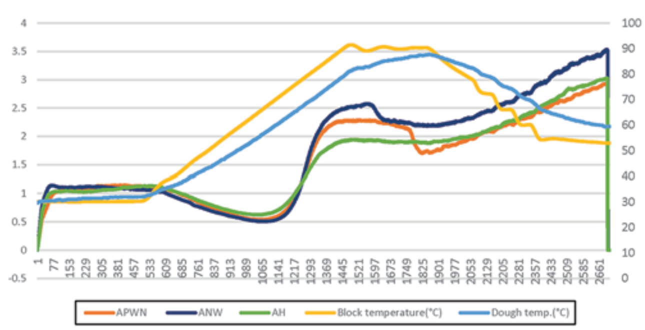

Fig. 3. Typical profiles of dough-mixing and starch-pasting properties of two partial waxy (medium grain Australian Noodle Wheat [ANW] and hard grain Australian Prime White Noodles [APWN]) and one "normal" starch (hard grain Australian Hard [AH]) Australian milling wheats. Data source: AEGIC.

There are two main areas of improvement that are the focus of breeders' attention. First, agronomic improvement to increase production levels and maintain the crop as an attractive option for farmers, and second, the ability to align quality characteristics with consumer preferences. Waxy gene characterization has impacted wheat development through its effective selection and use by breeding programs (10). Ultimately, by maintaining selection for a partial waxy genotype a breeding program can maintain a baseline quality profile from which further improvements in product performance can be built. Understanding the fundamental impact of partially waxy wheats on functional performance has been successful through combining scientific fields such as molecular biology, cereal chemistry, and applied breeding sciences to enable ongoing genetic improvements within Australian noodle wheat breeding programs. Perhaps it is no coincidence that the first molecular marker developed for wheat quality was one for a waxy gene, and the research was conducted in Western Australia, where there were ongoing efforts to breed for udon noodle wheats. This work has been developed further by researchers to expand the characterization of this gene and its homologues in wheat and other associated genes for granule-bound starch synthase I (GBSSI) proteins that are responsible for amylose synthesis and the three starch synthase II (SSIIa) enzymes involved in amylopectin synthesis (11,12). Molecular markers for these loci have been used extensively as an efficient approach to both maintain the quality characteristics of the noodle program, as well as facilitate the incorporation of new genetics into the program without large detrimental impacts on noodle quality.

Genetic gain is partly driven by program cycle time, so developing confident selection methods for quality performance for use early in the breeding pipeline allows for reduced time for new parent selection and increased germplasm improvement. Use of molecular markers for the waxy genes via traditional approaches has enabled some level of gain in this area. However, end-product quality is genetically complex and can be impacted by environmental influences (13), so the capacity to improve breeding pools and populations is more challenging than simply selecting for a few genes of major effect. Improving the performance of partially waxy wheat types requires the integration of this information into newer technology platforms, such as those that facilitate genomic selection.

Genomic selection is a relatively new methodology that is being broadly deployed across the plant- and animal-breeding communities for quantitative traits, including those related to cereal chemistry (14–16). It is an approach to marker-assisted selection in which genetic markers covering the entire genome are used along with their associated phenotypic information to create models to predict future performance. Integrating information on major genes, similar to those used to characterize partial waxy wheat, has been shown to improve the genomic selection approach (17,18). This approach is currently in development within the udon noodle wheat breeding program in Western Australia, with the markers for the GBSS alleles incorporated into a new genomic platform (Illumina XT chip reference) to facilitate forward selection for partial waxy types, along with genomic selection to account for residual variation in texture characteristics. Model development, however, requires the integration of quantifiable measurements of texture, for which methods are being developed to represent more traditional sensory evaluation approaches. Meanwhile, this approach can also benefit from the integration of complementary testing of small-scale samples, such as those used in the flour swelling volume (FSV) test (19) or use of near infrared (NIR) calibrations for flour paste viscosity. The integration of high-density genomic information and early generation testing into statistical models for selection are undergoing constant improvement. It is anticipated that reductions in the costs of DNA analysis will reach a level below the cost of other quality tests and replace their application in germplasm selection as selection accuracies increase.

Partial Waxy Wheats and Udon Noodle Quality

The quality of the starch component of wheat flour is an important factor influencing the eating quality of udon noodles in Japan and white salted noodles in South Korea. Other important factors include protein content and quality (20). The most important and critical last "test" in the Australian classification system for partial waxy ANW and APWN is the sensory assessment of Japanese udon noodles. It is often described as the test to confirm the "*mochi-mochi*" Japanese preference for the texture of udon noodles.

Sensory evaluation of noodles in Australia was developed some 30 years ago when major efforts were made to develop wheats suitable for the Japanese market. Panelists in Australia have undergone extensive training on udon noodles by experts from Japanese milling companies (19). The Australian Export Grains Innovation Centre (AEGIC) manages the sensory testing of Japanese udon noodles for classification of ANW and APWN. Udon noodles prepared for sensory evaluation are shown in Figure 4.

Sensory Evaluation of Udon Noodles

Udon noodles are synonymous with Japan and somewhat with Australia or, more precisely, Western Australia. The association exists with Japan because Japan is the "home" of udon noodles. For Western Australia, it is because of a long tradition of development and quality improvement of wheat varieties for udon noodle applications, which in 1989 resulted in the special ANW class segregation. In Australia, the development and segregation of a special noodle class has also led to the development of trained sensory panels and methods for assessment of wheat varieties. In 1992 Crosbie et al. (18) used Japanese Standard Methods to assess udon noodles (19,20). Udon noodles are cooked and prepared as per the standard method, recently also adopted as an AACC Approved Method for udon noodle preparation (21,22). In this test, udon noodles are served cold with soy sauce, and the appearance and eating quality of the boiled noodles is scored. After cooking, noodles are washed in cold and ice water and rested for 15 min before sensory assessment. Appearance is judged first, after which noodles are rinsed in water and revitalized before an eating assessment is performed. The appearance of boiled noodles is scored based on color (intensity of color development and brightness) and noodle surface appearance (rough versus smooth), while eating quality is scored based on the balance of firmness and softness, elasticity and stickiness, smoothness and flavor. The appearance of raw noodle sheets also is scored at time zero and 24 hr after noodle making. At time zero the noodle sheet is scored for color and brightness and at time 24 hr for discoloration and speckiness. A control sample is given set scores representing 70% of the total score possible for any given trait: boiled noodle color (17.5), surface appearance (14), balance of firmness and softness (7), balance of elasticity and stickiness (17.5), smoothness (7), flavor (7), and the raw noodle sheet (3) (23).

Fig. 4. Udon noodles prepared for sensory evaluation. Source: AEGIC.

For wheat noodle varieties to be classified as noodle wheats in Australia they must excel in both color and texture. In this process (typically used in the evaluation of new wheat lines) it is important that the selected control (standard) is representative of the best sample possible. Assessments by panelists are performed in silence, and results are discussed only when each panelist has completed the assessment (23).

Production of Noodle Wheats in Australia

Most of the Australian noodle wheat (ANW and APWN) is produced in Western Australia. Small pockets are produced on the Australian East Coast, typically wheat is contract grown for the domestic industry and small container export opportunities. Japan typically sources between 800,000 and 900,000 tonnes per annum of noodle wheat blend from Western Australia. Similar amounts of the noodle wheat blend each year are exported to the Korean market. The markets for ANW and APWN are currently limited to the Japanese udon and Korean white salted and *ramyon* noodles; thus, the production of this type of wheat needs to be carefully managed.

Future Trends

Wheat products in Australia have evolved from traditional white flour breads and noodles to a variety of products, including whole grains, high fiber, all-natural ingredients, etc. Whole grain and the use of ancient grains like quinoa are becoming more popular. Diversification in both wheat and wheat-based products will drive changes in the quality testing required and likely place greater emphasis on objective testing and use of new technologies to improve varietal selection.

Noodle Color. While there is no international standard method for noodle color measurement, there has been significant research providing guidelines for color measurement. Typically, there are two means by which noodle color is measured: the tristimulus method and the spectrometric method. One possible reason for the lack of a standardized approach for measuring noodle color is the considerable debate on how noodles should be presented to the instrument for measurement, including the background to be used, as well as noodle sheet thickness. In 2007, Solah et al. (22) suggested measuring the color of noodle sheets at infinite optical thickness, meaning that the color measurement is unaffected by the background color (thus using white, creamy, or black tiles as a background does not impact the readings). The color of boiled noodles can be assessed at infinite thickness using a method developed in 1991 by Crosbie (17). After boiling, rinsing, and draining, 60 g of noodles is placed in a plastic jar. An Agtron sample cup is used to compress the noodles before color measurement using the Minolta CRC-310 chroma meter (Fig. 5) (22).

Noodle Texture. Most noodle manufacturers and consumers in Asian countries rely on sensory panels to assess product quality. Such methods of assessment do not allow researchers to quantify the physical properties of noodles being analyzed. One of the main reasons why the instrument or objective assessment of noodle texture is not widely accepted by noodle manufacturers is the need for standardized preparation of noodles (including noodle making, boiling, and presentation for instrument texture measurement). In 2005, Ross and Hatcher reported on the importance of optimizing the conditions of noodle making and preparation before initializing evaluation of noodle texture (23).

The future of texture measurement of various types of Asian-style noodles might well be a combined approach or combination of tests that closely mimic the mouthfeel experienced by consumers when eating noodles (Fig. 6). Greater contributions to our understanding of instrument approaches for assessment of noodle texture were made in recent years by Hatcher and collaborators (24–27). Furthermore, Hatcher has recently made significant contributions to our understanding of ultrasonic techniques as one means of measuring the mechanical properties of noodles that relate to their texture. In 2010 and 2011,

Fig. 5. Minolta Chroma Meter measurement of boiled udon noodle color using an Agtron cup to compress 60 g of boiled noodles. Source: AEGIC.

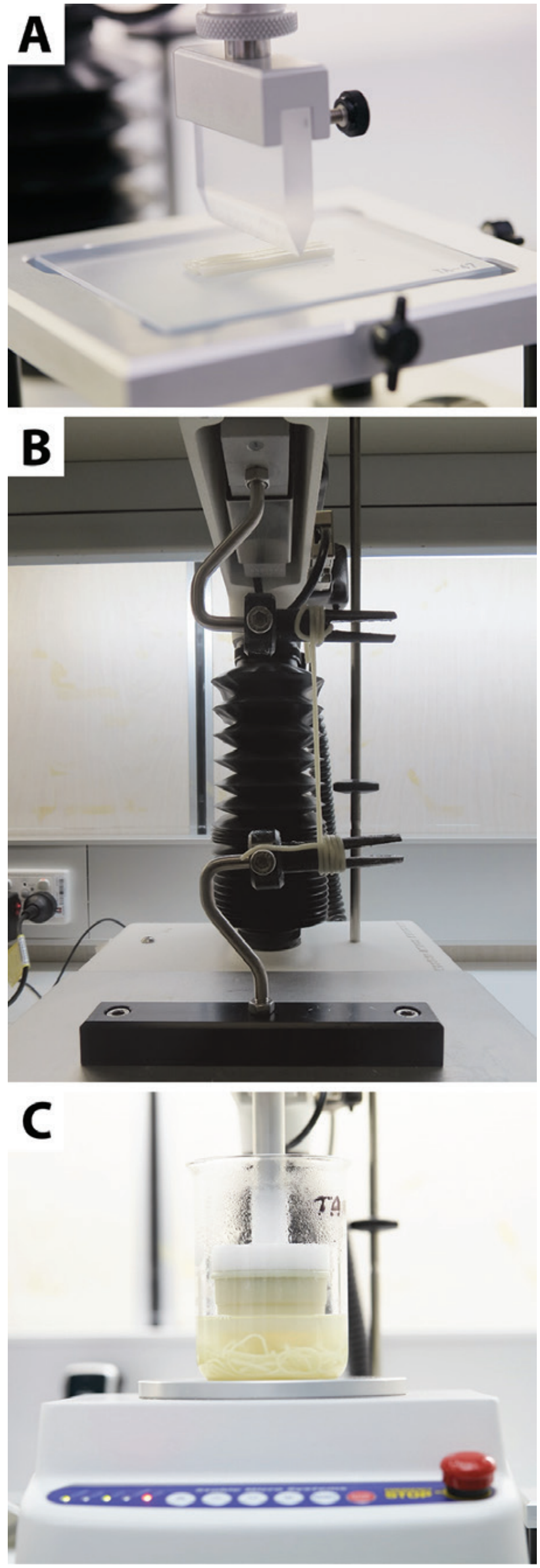

Fig. 6. Measurement of noodle firmness, chewiness, and extensibility using a texture analyzer (Stable MicroSystems). **A,** A flat probe (1 mm), most commonly used to measure firmness for udon noodle standards; **B,** tensile strength test measuring the extensibility of boiled noodle strands; **C,** new triple cutting ring system used to measure firmness of noodle strands with or without soup. Source: AEGIC.

Bellido and Hatcher demonstrated that measurements of sound velocity and attenuation can be used to study the rheological properties of noodles (28,29). In 2014, Diep and colleagues used this technique to discriminate raw noodle rheological properties as a function of wheat class and variety (30).

Quantifying sensory attributes, broadly described as mouthfeel is not an easy task. However, an exciting approach is being considered regarding modeling using information from the MixoLab, sensory and objective texture analyses to provide breeders and prebreeders with objective and quantifiable information for early quality selection.

Summary

In Summary, ANW and APWN are premium wheat classes grown in Australia, with unique high swelling properties of starch. Although the two share a number of similarities, they differ in their grain hardness and segregated protein content. They are blended to make up an Australian udon noodle blend. Agronomic improvement and alignment of varietal quality attributes with consumer preferences has led to a very successful 30 year partnership between Australian wheat growers and Japanese udon consumers. Genomic selection, while still a relatively new tool deployed by breeders, will likely lead to further improvements in the areas of quality, agronomy, and the speed of selection. Finally, the area of objective noodle texture combined with noodle dough rheology is being explored for the breeding and selection of ANW and APWN wheat lines.

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