The History of Durum Wheat Breeding in Canada and Summaries of Recent Research at the Canadian Grain Commission on Factors Associated with Durum Wheat Processing

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1. Abstract

The first part of this article reviews the history of durum wheat variety development in Canada, and how quality models are developed and continue to evolve in response to market feedback. Key technological factors that shaped durum wheat quality requirements in the 1950s through the 1980s were the adoption of the continuous vacuum extrusion process and Teflon die inserts, which placed greater emphasis on pasta appearance. In addition, there was growing awareness that stronger gluten is associated with firmer pasta texture. In the 1990s the use of high-temperature and ultra-high temperature drying of pasta placed even more emphasis on pasta color, and the increasing use of gluten index and alveograph as gluten strength specifications drove market preference to stronger gluten. Canada continued to release varieties that met these evolving market requirements, and as a result annual production of durum wheat in Canada rose steadily from an average of about 0.5 million metric tons (MMT) in the 1960s to 5 MMT today. The remainder of this article summarizes results of some research projects that reflect the scope of durum wheat research at the Canadian Grain Commission. The implications of gluten strength on pasta texture are examined, with particular attention to whether blending extra-strong gluten semolina into weak gluten semolina offers any advantage in pasta texture over blending with moderate strength semolina. In another project, pasta is enriched with high-fibre fractions from hull-less barley to improve nutrition. Impacts on pasta processing, color and texture will be examined. Two other projects explore the potential for developing multi-purpose durum wheat varieties that can be used for high volume bread and Asian yellow alkaline noodles (YAN), to broaden marketing opportunities. Deficiencies of durum wheat for making high volume bread typically are either inadequate strength, or inextensibility of stronger gluten genotypes. In a diverse world collection of durum wheat, strong genotypes with good extensibility were identified that produce high volume bread. Strong gluten durum wheat genotypes exhibited comparable YAN cooking quality to common wheat. Higher yellow pigment in durum wheat flour, combined with lower levels of polyphenol oxidase and peroxidase, make fresh durum wheat YAN superior to hard white spring wheat YAN for brightness, yellowness, and for color stability following processing.

Key words: durum wheat, quality screening, marketing, pasta, bread, Asian noodles.

2. Durum wheat breeding in Canada

2.1. Introduction

Canadian durum wheat is grown in the southern prairies of western Canada. This area has hot arid summers and light brown soil making it ideal for cultivation of durum wheat (Fig. 1). Canadian durum wheat is classified into four Canada Western Amber Durum (CWAD) wheat milling grades using grade standards set by the Canadian Grain Commission on the basis of scientific research (Dexter and Edwards, 1998). The intrinsic quality of CWAD is assured by the requirement that only varieties that conform to a set quality model are registered.

The quality model for Canadian durum wheat varieties evolves in response to feed back from CWAD customers. The history of Canadian durum wheat breeding was described in detail by Dexter and Marchylo (1997) ten years ago. This article briefly summarizes highlights up to that time, followed by an update on progress in durum wheat variety development in Canada over the past ten years.

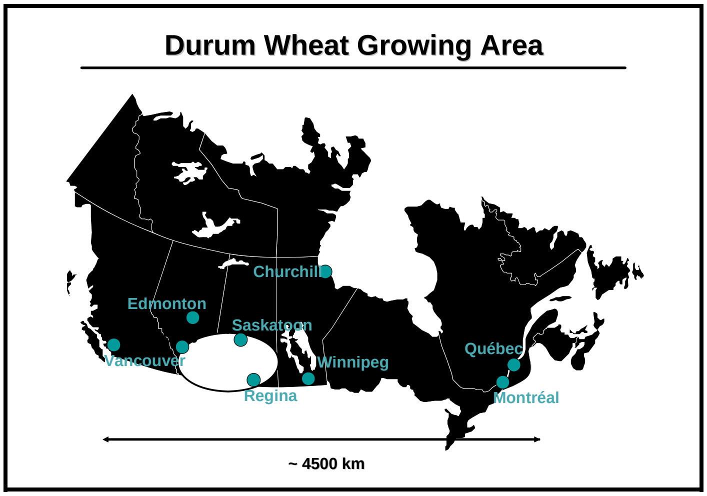

Fig. 1. Canadian durum wheat is grown primarily in the southern prairies (the circled area above) where summers are hot and arid.

2.2. Historic milestones in Canadian durum wheat breeding

Durum wheat was introduced into western Canada in the late 19th Century, but the first variety developed in Canada, Stewart 63, was not released until 1963. Durum wheat production surged in the 1960s because of a stem rust epidemic in western Canada (Fig. 2). Durum wheat was less susceptible to stem rust than bread wheat varieties available at that time.

By today's standards Stewart 63 was poor quality. Gluten was weak, yellow pigment content was low, and pasta texture was poor (Table 1). Customers made it clear that CWAD quality needed improvement. Modern pasta-making technology made color of increasing importance for premium pasta. Continuous automatic extrusion under vacuum produced a bubble-free product with great depth of color, and Teflon die inserts gave pasta a smoother and brighter surface. Thus, initially efforts to improve Canadian durum wheat quality centered on improving yellow pigment levels and pasta brightness.

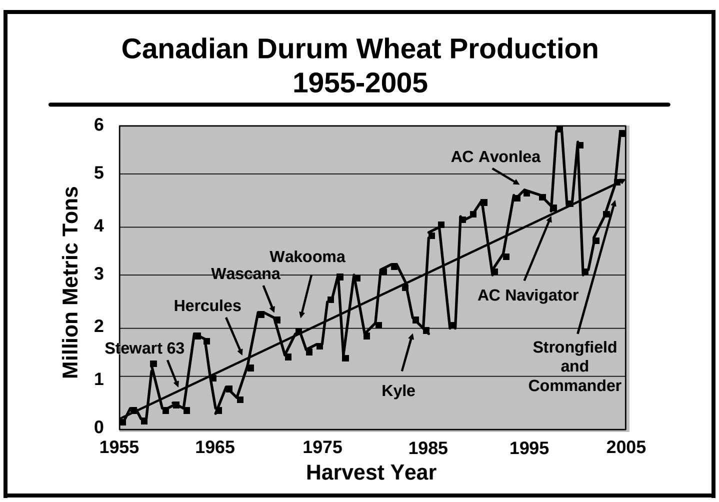

Fig. 2. Production of Canadian durum wheat over the past 50 years, with the date of registration of important varieties indicated.

Italy, an important durum wheat market for Canada, drove awareness that strong gluten was an important determinant of pasta firmness. Pelissier, a variety introduced from North Africa in 1929, had much stronger gluten than other CWAD varieties registered at that time. Pelissier was segregated into a special grade, Extra No 4 CWAD, beginning in 1955 because of poor color (Table 1). Extra No 4 CWAD was preferred by Italy over other CWAD grades because of superior strength. Therefore, improving gluten strength of CWAD became an additional priority.

The first Canadian variety that combined better color and stronger gluten than Stewart 63 was Hercules, registered in 1969 (Table 1). Two other improved varieties, Wascana and Wakooma, were registered in 1971 and 1973, respectively. Wascana and Wakooma had better agronomic properties than previous CWAD varieties, and comprised over 75% of land seeded to CWAD by the late 1970s. Improved CWAD quality made Canada a preferred supplier of durum wheat in high quality markets, and resulted in annual production of over 2 million metric tons (MT) by the late 1970s (Fig. 2).

Table 1. Some properties of cultivars from the 1969 Canadian durum wheat breeding program.

Properties	Stewart 63	Pelissier	Hercules	Wascana	Wakooma
Wheat:					
Protein, %	13.9	14.2	14.8	13.8	14.4
Semolina					
Gluten stretch, min	4	>300	42	34	>300
Spaghetti					
Pigment, ppm	4.3	3.6	5.5	6.7	5.6
Cooking score, units	5	14	12	16	24

Kyle, a variety of similar gluten strength to Wakooma, but higher yellow pigment content and better agronomic properties, was registered in 1984. Kyle quickly became the dominant CWAD variety, and accounted for over 50% of CWAD seeded area throughout the late 1980s and throughout all of the 1990s. During this period CWAD production continued to increase. Average annual production was in excess of four million MT by the mid 1990s (Fig. 2).

2.3. Recent progress in Canadian durum wheat breeding

The introduction of high temperature (HT) drying (60^{o}C to 80^{o}C) and ultra-high temperature (UHT) drying (80^{o}C to 110^{o}C) of pasta (Pollini, 1996) have influenced durum wheat quality specifications in recent years. HT and UHT drying produce pasta of acceptable or even superior cooking quality from mediocre quality raw material (Malcolmson et al., 1993). HT and UHT drying can also improve pasta color, but care must be taken to ensure that Maillard (non-enzymatic) browning reactions are minimized (Dexter et al., 1984). Gluten strength has less influence on the cooking quality of HT and UHT pasta compared to LT pasta (D'Egidio et al., 1990). Nevertheless, gluten strength remains an important durum wheat specification. Gluten index (Cubadda et al., 1992) and physical dough tests, particularly the mixograph and the alveograph, are widely used (Dick and Youngs, 1988; D'Egidio et al., 1990).

A major durum wheat breeding breakthrough was the discovery by Damidaux et al. (1978) that two γ-gliadin proteins, designated 42 and 45 when separated by electrophoresis, are markers for weak and strong gluten, respectively. Stewart 63 and Wascana are γ-gliadin 42 genotypes. Hercules, Wakooma and all varieties of CWAD registered since Wakooma are γ-gliadin 45 genotypes. It is now known that the actual cause of strong gluten in γ-gliadin 45 genotypes is a specific group of low molecular weight (LMW) glutenin subunits, designated as LMW-2 (Pogna et al., 1988).

LMW-2 durum wheat genotypes have a wide gluten strength range. Evidence that LMW-2 genotypes are superior in cooking quality to LMW-1 (γ-gliadin 42) genotypes is conclusive (Kosmolak et al., 1980), but evidence that stronger LMW-2 genotypes exhibit superior pasta cooking quality to weaker LMW-2 genotypes is not (Marchylo et al., 2001). Modern CWAD varieties exhibit comparable cooking quality, despite a wide strength range (Table 2). Regardless, to satisfy some international customers it was decided in the mid-1990s to increase CWAD gluten strength. AC Avonlea, which has gluten strength similar to Kyle, was registered in 1997 because stronger lines had not yet advanced to the final stages of breeding trials. AC Avonlea exhibited improved protein content and better color, and quickly became the most popular CWAD variety due to superior agronomics. All CWAD varieties registered since 1997 have significantly stronger gluten than AC Avonlea.

Table 2. Some properties of cultivars from the 2005 Canadian durum wheat breeding program.

Properties	AC Avonlea	AC Navigator	Strongfield	Commander
Wheat:				
Protein, %	14.6	13.8	14.8	13.7
Cadmium, mg/kg	0.167	0.213	0.073	0.248
Semolina				
Pigment, ppm	8.3	9.5	8.8	9.8
Gluten index, %	34	74	71	94
Alveograph				
P/L	0.58	1.52	1.04	1.68
W, J x 10^{-4}	147	276	260	363
Spaghetti firmness (dried at 90^{o}C)				
Optimum cooking time, g	1185	1125	1238	1138
Overcooked, g	783	794	805	808

Also in 1997, AC Navigator and AC Pathfinder were approved for test marketing. They exhibited much stronger gluten than previous CWAD varieties, so were identity preserved as ‘Extra-Strong’ CWAD. AC Navigator also possessed more yellow pigment than previous varieties. Its greater pigment content and higher semolina yield resulted in more favorable response from customers than AC Pathfinder. Accordingly, in 2001 registration of AC Navigator was extended and that of AC Pathfinder was withdrawn. AC Navigator was marketed exclusively identity preserved to take advantage of its attributes until 2005, when it was granted full registration, allowing the option of blending it with other CWAD varieties. In 2004, AC Commander, a variety with exceptionally strong tenacious gluten, and yellow pigment content similar to AC Navigator, was registered. (Table 2). Commander is being marketed identity preserved to assess customer reaction before making a final decision on whether to blend with CWAD varieties.

A food safety issue that affected the Canadian durum wheat breeding program is the level of the heavy metal cadmium in durum wheat. Codex Alimentarius have proposed a maximum level of 200 mg/kg in wheat. It was discovered ten years ago that most CWAD lines have high cadmium levels. CWAD export shipments met international limits, but monitoring was required to assure compliance. Therefore, reduction of cadmium levels in durum wheat became a primary Canadian breeding objective. Cadmium in durum wheat is controlled by a single dominant gene (Clarke et al., 1997). Low cadmium is highly heritable and the low cadmium allele lowers cadmium by about 50% without significant effects on agronomy or quality. By 2005 all advanced lines in the Canadian durum wheat breeding program had the low cadmium allele, and low cadmium is now mandatory for registration of durum wheat cultivars in Canada. A major breakthrough was the registration of Strongfield, a strong gluten low cadmium variety, in 2004 (Table 2). Strongfield has outstanding agronomics, and became the leading CWAD variety by 2007, so the level of cadmium in CWAD exports is no longer an issue.

3. Effect of blending durum wheat varieties of variable gluten strength on pasta texture

3.1. Introduction

Some pasta manufacturers blend durum wheat and/or semolina to maintain consistent strength. Advantages of blending include more consistent processing characteristics, more consistent final product, and reduced cost if semolina with very strong gluten is used in blends with inexpensive weak gluten semolina. There is no conclusive evidence that stronger gluten LMW-2 durum wheat genotypes have better pasta texture than weaker gluten LMW-2 genotypes (Table 2). However, stronger LMW-2 genotypes may offer advantages when blended with weak LMW-1 durum wheat genotypes.

3.2. Samples and experimental

Stewart 63 and contemporary registered CWAD varieties with a wide range of gluten strength were milled into semolina (Dexter et al., 1990). Semolina from each CWAD variety was blended into Stewart 63 at five levels (Table 3). Gluten index (GI) and alveograph were determined by AACC (2000) Approved Methods. Spaghetti was prepared by a micro-procedure (Matsuo et al., 1972) and dried at HT (70^{o}C) (Dexter et al., 1981) and UHT (90^{o}C) (Dexter et al., 1984).

3.3. Results and discussion

The alveograph is a popular semolina strength specification. When AC Navigator semolina was blended into Stewart 63 semolina, alveograph curves became progressively stronger as the amount of AC Navigator increased (Fig. 3). Plenty, a weaker LMW-2 genotype, affected alveograph curves much less.

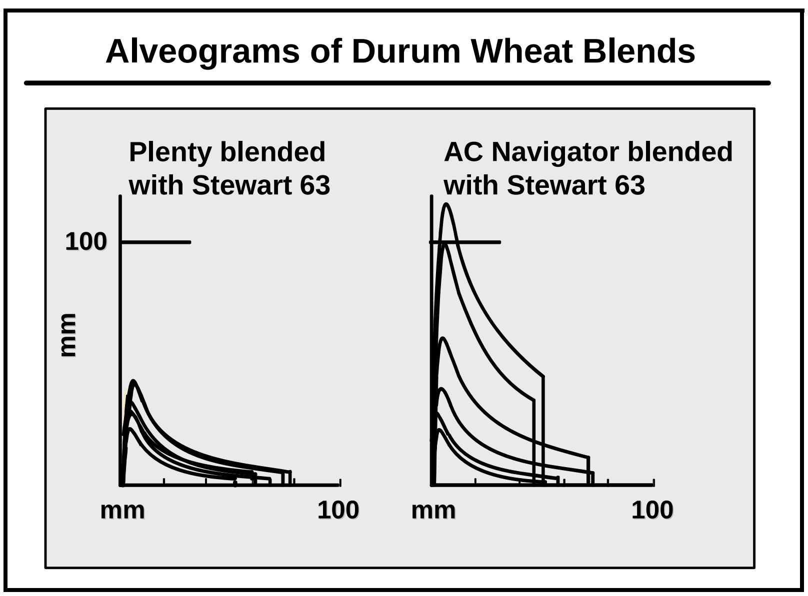

Fig. 3. Alveograph curves obtained from 100% Stewart 63 semolina, and from various blends of Stewart 63 semolina with semolina from the Canadian durum wheat varieties Plenty and AC Navigator.

GI discriminates among medium strong to extra strong varieties, but gives anomalously low results for moderate strength varieties. For example, Plenty has a GI of 3% (Table 3), which understates its gluten strength as measured by alveograph (Fig. 3). This raises the question whether GI improves when strong gluten semolina is blended with weak semolina in relatively low proportions. When the stronger CWAD varieties, AC Navigator and AC Melita, were blended with Stewart 63, GI increased incrementally as the proportion of stronger durum increased (Table 3). These results confirm that strong gluten durum wheat genotypes can be used effectively in blends by semolina millers to meet GI specifications.

Table 3. Gluten index of various blends of CWAD varieties with Stewart 63.

	Blend level				
Variety	15%	30%	50%	75%	100%
Stewart 63	--	--	--	--	3
Plenty	2	3	2	4	3
AC Melita	4	10	38	64	77
AC Navigator	4	20	44	78	89

As discussed previously, there seems to be little benefit to pasta cooking quality when gluten strength of LMW-2 genotypes is increased, particularly when drying by HT or UHT. In this study differences in pasta firmness made from 100% of a given contemporary Canadian cultivar were not statistically significant by either HT or UHT (Fig. 4). All exhibited superior pasta firmness compared to 100% Stewart 63 semolina. Greater gluten strength for LMW-2 genotypes does appear to be beneficial to cooking quality when blending with weak semolina. Whether spaghetti was dried at 70°C or 90°C, cooking quality rankings of blends with Stewart 63 at blend levels up to 75%, were generally in order of gluten strength: AC Navigator > AC Melita > Plenty. The variation in strength among LMW-2 genotypes is due to higher LMW glutenin content (Edwards et al., 2007a). LMW-2 glutenin is the gluten protein fraction associated with pasta texture. The stronger LMW-2 genotypes contribute more LMW-2 glutenin at comparable blend levels than weaker LMW-2 genotypes, accounting for superior pasta cooking quality of the blends with stronger genotypes.

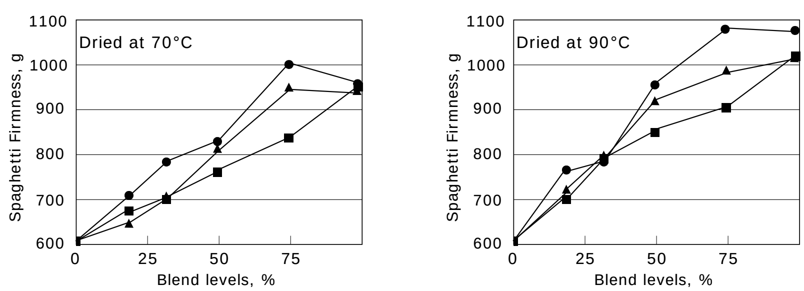

Fig. 4. Firmness of pasta prepared from various blends of Stewart 63 semolina with semolina from the Canadian durum wheat varieties Plenty (■), AC Melita (▲) and AC Navigator (●).

3.4. Conclusions

Alveograph curves discriminate better between durum wheat genotypes of weak to moderate gluten strength than GI. Pasta firmness does not improve as strength increases when pasta is prepared from 100% semolina from LMW-2 genotypes, whether dried at HT or UHT. However, when semolina from stronger LMW-2 genotypes is blended into semolina from a very weak LMW-1 genotype, cooked spaghetti firmness was improved more than for weaker LMW-2 genotypes at the same blend level.

4. Pasta containing fibre-rich hull-less barley fractions

4.1. Introduction

Hull-less barley cultivars are available with zero amylose waxy, waxy, 'normal' amylose and high amylose starch, elevated levels of beta-glucans and arabinoxylans, and other important nutrients (Izydorczyk et al., 2003). Diverse starch pasting characteristics, and potential health benefits, have aroused considerable interest in using hull-less barley and hull-less barley fractions as food ingredients. β-glucans, the major fibre constituents in barley have proven health benefits (Brennan and Cleary, 2005). Recently the US Food and Drug Administration (FDA), allowed whole grain barley and barley-containing products to carry a claim that they reduce the risk of coronary heart disease (FDA, 2005).

Izydorczyk et al. (2003) reported a simple roller milling procedure that readily separates hull-less barley into flour and a fibre-rich fraction (FRF). The FRF has been successfully incorporated into Asian noodles (Izydorczyk et al., 2005). Here we summarize results from a study incorporating barley FRF into pasta (Dexter et al., 2005).

4.2. Samples and experimental

The hull-less barley genotypes used were the Canadian varieties CDC Alamo (zero amylose starch) and Falcon (normal amylose starch, 24% amylose), and the experimental line CDC-92-55-06-48 (high amylose starch, 42% amylose). Barley was conditioned to 14.5% moisture, pearled 15%, and roller milled by a short flow according to Izydorczyk et al. (2003). The base semolina used was derived from AC Avonlea durum wheat.

Protein, starch and β-glucans contents and pasta texture were determined by AACC (2000) Approved Methods. Arabinoxylans were determined according to Douglas (1981). Amylose of defatted starch was determined by potentiometric titration (Schoch, 1964). Semolina was enriched at designated levels with FRF, processed by a micro-procedure of Matsuo et al. (1972), and dried at 70°C (Dexter et al. 1981). Pasta color was determined as described by Dexter et al. (2004).

4.3. Results and discussion

β-glucan contents of the genotypes were 8.1% (high amylose), 7.1% (zero amylose) and 3.9% (normal amylose). In agreement with Bhatty (1999), flour yield was inversely related to beta-glucans content (not shown), which resulted in a positive relationship between FRF yield and β-glucans content (Table 4). FRF yield ranged from 12% for the normal amylose barley to 27% for the high-amylose barley. β-glucans were concentrated over two-fold in the FRF compared to whole barley, with concentrations ranging from 10.3% for normal amylose FRF to 18.3% for high amylose FRF. Arabinoxylans were in comparable amounts in FRF for all genotypes, averaging about 8%.

Table 4. Yield and composition of hull-less barley FRF (analytical values on dry matter basis).

Starch type	FRF yield, %	Starch, %	Beta-glucans, %	Arabinoxylans, %	Protein, %N X 5.7
High amylose	27	50.9	17.3	8.6	14.6
Normal amylose	12	57.7	10.3	8.3	13.3
Zero amylose	21	49.4	18.3	7.3	15.0

Sufficient FRF was added to increase spaghetti β-glucans content by 2% (Table 5). Spaghetti processed normally except water absorption was 34% for the zero-amylose FRF blend and 36% for the other blends compared to 30% for 100% semolina. The greatest effect on spaghetti color was observed for the normal amylose genotype, because twice as much FRF was required to achieve comparable enrichment of β-glucans. Adding FRF decreased spaghetti brightness (L*) and yellowness (b*), increased redness (a*), and increased speckiness (not quantified). However, color of spaghetti from high amylose and zero amylose FRF-semolina blends was still reasonably satisfactory, and should be acceptable to health conscious consumers. Cooked spaghetti firmness was not significantly influenced by adding FRF, despite dilution of wheat gluten, suggesting that β-glucans and/or arabinoxylans and/or hull-less barley protein contribute positively to cooked spaghetti firmness.

Table 5. Color and firmness of spaghetti produced from FRF-semolina blends.

Sample	FRF added, %	L*	a*	b*	Firmness, g
Semolina	0	76.6	2.7	63.3	1028
High amylose	11	67.9	6.8	50.7	1073
Normal amylose	20	61.1	10.6	45.8	1053
Zero amylose	11	68.4	6.5	52.1	1102

4.4. Conclusions

Spaghetti enriched with FRF processed normally with the exception that dough water absorption needed to be increased. Color of FRF-enriched spaghetti was inferior to 100% durum wheat semolina spaghetti, but still acceptable. Spaghetti firmness was not affected by addition of FRF. These results show that barley FRF derived by roller milling, which is produced without any chemicals, has enormous potential as a natural raw material to increase dietary fibre in pasta.

5. Baking quality of a world collection of durum wheat varieties

5.1. Introduction

Durum wheat has a long history of use for traditional flat breads and specialty breads in Mediterranean countries (Quaglia, 1988). There is interest in developing durum wheat suited to high volume breads to provide alternative markets during periods of overproduction (Liu et al., 1996). Durum wheat baking performance improves as gluten becomes stronger, but strong durum wheat tends to have tenacious gluten, which imparts inextensible dough and limits loaf volume due to reduced oven response (Quaglia, 1988).

Durum wheat breeding programs select lines for quality solely on the basis of pasta-making potential, because pasta is the most important end product. Therefore, durum wheat baking potential has been an afterthought, which may, in part, explain why previous studies have consistently concluded that durum wheat baking quality is intrinsically inferior to bread wheat. In this study, we investigated the baking quality of durum wheat genotypes from diverse origins with a range of gluten strength and protein composition, to determine the potential range of durum wheat baking quality (Edwards et al., 2007b).

5.2. Samples and experimental

Thirty genotypes from Argentina, Australia, Canada, France, Germany, Italy, New Zealand, Russia, Spain, and USA were grown in western Canada in 2001 and 2002. Samples were milled into semolina by the method of Dexter et al. (1990). Gluten index (GI), alveograph and farinograph were determined by AACC (2000) Approved Methods. Hearth bread was prepared by the procedure of Paulley et al. (2004). Unextractable polymeric protein (UPP) content was determined as described by Gupta et al. (1993). Polyacrylamide gel electrophoresis (PAGE) of HMW-GS was conducted using the SDS-PAGE method of Gupta and MacRitchie (1991). The presence of γ-gliadin 42 or 45 markers for LMW-1 or LMW-2 glutenin patterns were determined by using acid-PAGE (Tkachuk and Mellish, 1980).

5.3. Results and discussion

Among the genotypes three were LMW-1 types. HMW glutenin subunits (GS) patterns identified among the 27 LMW-2 genotypes included 6+8, 7+8, 7+16, 14+15, 20 and 2*+20. There is no conclusive evidence that HMW-GS patterns are related to durum wheat gluten strength with the exception of HMW-GS 20, which has been reported to correlate to weak gluten (Carillo et al., 1990).

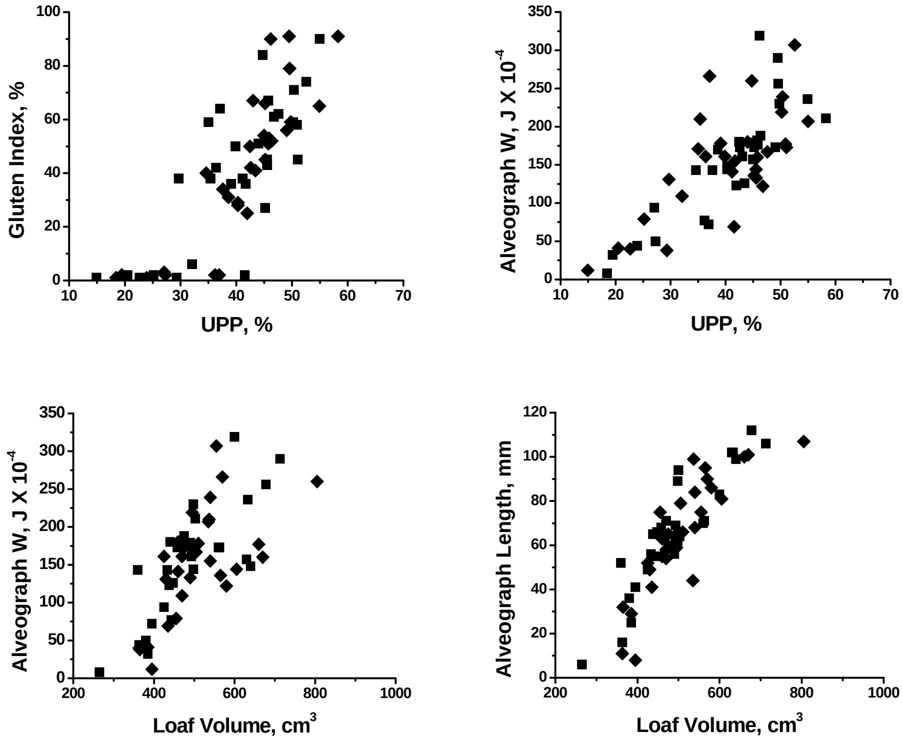

Fig. 5. Relationship of UPP to gluten index (upper left) and alveograph W (upper right) and relationship of loaf volume to alveograph W (lower left) and alveograph length (lower right).

The proportion of UPP protein was strongly and linearly related to dough strength as measured by alveograph W (Fig. 5). GI was also correlated to UPP, but as indicated previously, did not discriminate well for moderate to strong genotypes. Loaf volume was strongly correlated to alveograph W, confirming the advantage of strong gluten for bread-making. However, alveograph L was more strongly correlated to loaf volume, demonstrating that strong cultivars with more extensible dough give the best bread. Some of the durum wheat genotypes made hearth bread equal to or superior in both volume and crumb structure to that produced by a Canada Western Red Spring wheat bakery flour of comparable protein content (Fig. 6). A negative baking quality aspect for even the strongest and best performing durum wheat genotypes is lack of fermentation tolerance compared to common wheat (Sapirstein et al., 2007), necessitating substantially lower baking absorption to maintain adequate handling properties of durum wheat dough, particularly for long fermentation baking processes. All of the LMW-1 genotypes made very poor bread due to weak dough properties. Among the LMW-2 genotypes, those containing HMW-GS 20 were consistently low in UPP and poor in baking quality.

5.4. Conclusions

Durum wheat baking quality is positively associated with gluten strength and UPP content. Durum wheat genotypes with HMW-GS 20 tend to be weak and of inferior baking quality. Some strong durum wheat genotypes exhibited good balance between dough elasticity and extensibility and produced hearth bread equal in volume and appearance to that of high quality bread wheat. These results show that by screening for baking quality in durum wheat breeding programs, it should be possible to develop dual purpose (pasta/bread) durum wheat varieties.

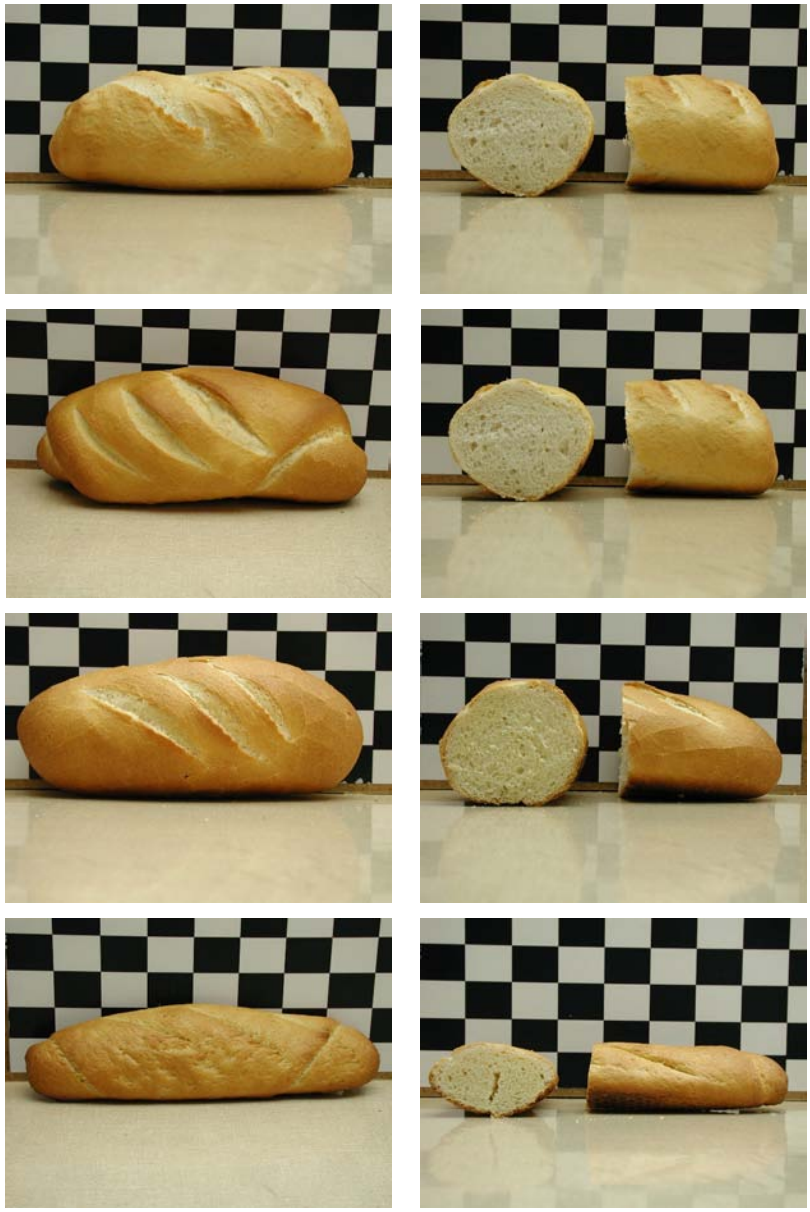

Fig. 6. Bread from a CWRS control flour compared to bread from some of the durum wheat LMW-2 genotypes harvested in 2001. CWRS control (top row), HMW-GS 6+8 (2nd row), HMW-GS 7+8 (3rd row), HMW-GS 20 (bottom row).

6. Yellow alkaline noodle quality of durum wheat

6.1. Introduction

Another possible use for durum wheat which has been relatively unexplored until very recently is for yellow alkaline noodles (YAN) (Fu et al., 2006). YAN dominates Asian markets, accounting for about 35% of flour consumption (Hatcher, 2001). Asian noodles are sheeted and cut from fresh dough. The formula is simple: flour, water, alkaline salts and sodium chloride, the concentration of salts and the ratios of potassium and sodium carbonates varying depending on local taste (Hatcher and Anderson, 2007).

Yellowness of YAN prepared from common wheat flour is primarily derived from endogenous flavonoids which are colorless in flour, but undergo a chromophoric shift, and turn yellow in the presence of alkaline

(Asenstorfer et al., 2006). YAN are usually purchased fresh daily, with consumer choice being primarily dependant on visual appearance (color intensity, brightness and absence of visible specks). Stability of color of fresh YAN is a major marketing factor, good color stability being favored by low oxidative enzyme activity (polyphenol oxidase and peroxidase) (Miskelly, 1984). The high yellow pigment content of durum wheat, combined with low oxidative enzyme activity would suggest application as a YAN raw material. Here some recent GRL research on suitability of some Canadian durum wheat genotypes for YAN production is summarized (Hatcher et al., 2008a, 2008b).

6.2. Samples and experimental

Flour of approximately 74% extraction from commercially produced Canada Western Red Spring (CWRS) wheat and Canada Western Hard White Spring (CWHWS) wheat, and field plot samples of the Canadian durum wheat varieties Avonlea, Strongfield and Commander were used for this study (Table 6). Protein, gluten index, yellow pigment and starch damage were determined by AACC (2000) Approved Methods. Flavonoids were determined as described by Hatcher et al (2008a). Polyphenol oxidase activity and peroxidase activities were determined as described by Hatcher and Kruger (1993) and Hatcher and Barker (2005), respectively. Noodles were prepared (Kruger et al., 1994), noodle texture and color were determined (Hatcher et al., 2005) and specks were counted (Hatcher et al., 2004) by established Canadian Grain Commission methods.

Table 6. Flour properties.

Property	CWRS	CWHWS	Avonlea	Strongfield	Commander
Protein, %	13.1	13.2	13.6	12.6	13.2
Gluten index, %	93	96	51	67	96
Yellow pigment, ppm	3.0	2.2	5.7	8.4	8.7
Flavonoids, units	0.11	0.09	0.15	0.16	0.17
Starch damage, %	6.8	6.6	17.2	14.9	18.4

6.3 Results and discussion

On the basis of gluten index, the durum wheat flours ranked in strength from very strong (Commander, comparable to the common wheats) to moderate (AC Avonlea) (Table 6). As expected, the durum wheat flours exhibited significantly higher yellow pigment content than the hard common wheat flours. The durum wheat flours also contained higher flavonoid levels. The very hard nature of durum wheat was clearly evident by much higher flour starch damage levels.

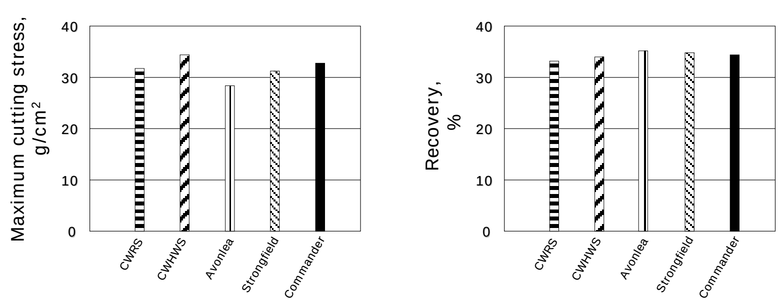

Fig. 7. Maximum cutting stress and recovery of durum wheat yellow alkaline noodles compared to hard red spring and hard red winter wheat.

Cooking quality of YAN produced from all of the durum wheat genotypes was comparable to the common wheat flour YAN (Fig. 7), despite the higher starch damage of the durum wheat flours. This was consistent with Hatcher et al. (2008c), who reported that the benefit of fine particle size outweighed the negative impact of high starch damage in determining YAN texture.

All durum wheat genotypes exhibited brightness (L*) equal to or better than CWRS and CWHWS at 2 hr after processing, and much superior brightness 24 hr after processing (Fig. 8), due to very low levels of oxidative enzymes in the durum wheat flours. Polyphenol oxidase (PPO) was not detectable in the durum wheat flours, whereas PPO activities were about 20 nmoles O_2/g/min for the common wheat flours. Peroxidase levels were an order of magnitude lower than in the common wheat flours (not shown). The durum wheat YAN were much more yellow than either common wheat YAN, due primarily to higher yellow pigment, although higher flavonoid levels may also be a factor. The durum wheat YAN were slightly more red than the common wheat YAN, perhaps due to more intense pigmentation.

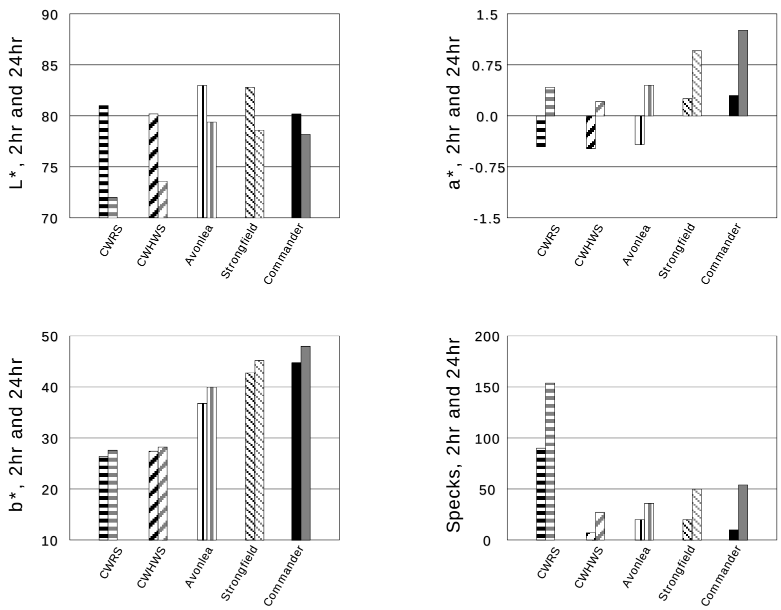

Fig. 8. Brightness (L*), redness (a*), yellowness (b*) and specks per 25 cm^2 for durum wheat yellow alkaline noodles compared to hard red spring and hard red winter wheat 2hr (left) and 24hr (right) after processing.

White wheat is preferred for YAN over red wheat because bran specks are less visible in the former (Ambalamaatil et al, 2002). The advantage of CWHWS over CWRS due to lower number of visible specks is clearly evident in this study (Fig. 8). The durum wheat YAN also exhibited clear advantages in number of visible specks when compared to CWRS.

6.4 Conclusions

Durum wheat has enormous potential as a raw material for YAN, either alone or in blends with common wheat flour. Cooking quality is comparable to common wheat YAN of similar protein content, and a combination of high yellow pigment and low oxidative enzyme activity gives durum YAN superior brightness and yellowness, and better color stability post production.

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