Recent Trends in Durum Wheat Milling and Pasta Processing:
Impact on Durum Wheat Quality Requirements

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SUMMARY

Durum wheat quality criteria continually evolve in response to market pressure and consumer preference. Increasing demand for specific durum wheat quality attributes for different end-products requires development of more rapid objective means to grade and classify wheat parcels on the basis of processing potential. Near-infrared spectroscopy and image analysis have considerable potential for rapid objective wheat grading and classification. Preprocessing (debranning before milling) enhances durum wheat milling performance. Surface discolourations, major factors in grading durum wheat because of negative impact on semolina colour and presence of visible specks, will become less important if preprocessing becomes more accepted by durum wheat millers. Semolina granulation has become finer to accommodate large high capacity pasta presses and Polymatik presses. The move to finer granulation, particularly when protein content is specified, makes hard vitreous kernel content of less importance to durum wheat millers. Intense competition in the pasta industry has made pasta colour, an important aesthetic factor in consumer choice, more universally important. That, combined with a trend to higher semolina extraction rates, will require plant breeders to develop durum wheat varieties with higher levels of yellow pigment and lower levels of oxidative enzymes. High temperature (HT) and ultra-high temperature (UHT) drying have become the processes of choice for most pasta manufacturers. Strong gluten is likely to remain an important specification in some markets even though it appears to have less influence on cooking quality for HT and UHT pasta that for low temperature-dried pasta. Regardless of drying temperature, protein content will continue to be a fundamental requirement to ensure good pasta cooking quality. There is increasing interest in using durum wheat for baking. Durum wheat baking quality does not appear to be linked to pasta cooking quality, giving hope for development of durum wheat varieties suitable for both pasta-making and bread-making.

Key Words: Durum wheat; grading; classification; milling; pasta-making; bread-making

INTRODUCTION

The concept of durum wheat quality is complex and confusing. Quality factors such as protein content, gluten strength and colour have different priorities in various durum wheat markets. Durum wheat quality criteria are continually evolving in response to technological advances in durum wheat milling and secondary processing.

Globilisation and increasing competition in the pasta industry are making it more important that processors produce pasta products with quality that is consistent over time. Customers are becoming more discriminating in their quality requirements, and variability in product quality is becoming less acceptable, particularly for premium products.

The future challenge will be to implement durum wheat variety development, production and grain handling systems capable of consistently producing and segregating wheat that meets the demand of modern processing technology. Producers must grow varieties of good intrinsic quality, and wheat must be segregated efficiently according to physical condition and specific quality attributes.

This presentation will examine recent trends in durum wheat segregation, semolina milling, pasta processing and bread-making, in response to evolving market needs. Important durum wheat quality factors will be identified, and their significance will be considered in light of technological advances in durum wheat processing and changing consumer preferences.

WHEAT GRADING AND CLASSIFICATION

Wheat class and physical condition are the most important factors determining wheat milling potential and end-product quality (Dexter and Edwards 1998a and 1998b). Depending on the intended end-use, a wheat class may be hard or soft, high protein or low protein, strong gluten or weak gluten (Dexter 1993). Accordingly, most wheat producing countries have grading and classification systems in place. An effective grading and classification system assigns and preserves the commercial value of wheat parcels on the basis of processing potential, while also satisfying producers by giving the best possible return.

Within a wheat class intrinsic quality will also vary. In the case of durum wheat, important quality differences include semolina milling potential, protein content, semolina and pasta colour, gluten strength and pasta cooking quality. To assure quality, semolina millers and pasta manufacturers provide specifications to suppliers. In some cases this may include guarantees of variety composition in a shipment.

High throughput wheat receiving facilities require that grading and classification be performed rapidly. Therefore, traditionally, wheat grading and classification have been done primarily visually. Test weight, which is strongly associated with durum wheat milling performance (Dexter et al. 1987), can be determined rapidly, and is well established as an objective grading factor. The development of rapid objective procedures that classify wheat according to functionality would be of great benefit to producers, grain handlers, wheat millers and processors.

Near-infrared spectroscopy (NIRS) was the first rapid instrumental technique to find broad application in the grain industry. In the 1970s rapid and accurate determination of moisture content and protein content in grain by NIRS became widely accepted. NIRS made segregation of wheat parcels by protein content practical, facilitating protein guarantees on wheat shipments (Williams et al. 1978; Williams and Cordeiro 1981). In Canada, NIRS is used to segregate Canada Western Amber Durum (CWAD) wheat by protein content in grain handling facilities, and at customer request CWAD can be shipped at predetermined guaranteed protein levels.

Delwiche and Massie (1996) found that rapid single kernel visible and near-infrared (NIR) reflectance spectroscopy has potential in wheat classification, and the detection of admixtures of classes. NIRS has the potential to predict functionality as well as composition of wheat (Pawlinsky and Williams 1998). NIRS has been used to predict *Fusarium* damage and the associated mycotoxin, vomitoxin (Dowell et al. 1999). According to Williams (1999 and 2000a) NIRS has the potential to assign grades electronically on the basis of factors such as frost, surface discoloration, sprout damage, and *Fusarium* damage.

There are a number of examples showing the potential of NIRS as an aid in durum wheat grading and classification. Whole grain NIRS has potential for prediction of durum wheat semolina yield (Ripetti-Ballester et al. 2000). Edwards et al. (1996) demonstrated that durum wheat yellow pigment could be predicted on whole grain by visible-NIR spectroscopy, potentially allowing segregation of durum wheat according to pasta colour potential.

Hard vitreous kernels (HVK), an important grading specification in durum wheat because it is associated with hardness and semolina yield, is a tedious visual procedure (ICC 1999). Dowell (2000) found that whole grain NIRS classified obviously vitreous and non-vitreous durum wheat kernels in perfect agreement with grain inspectors. However, he correctly classified only 75% when more difficult-to-classify kernels were present. Dexter et al. (1988) found that the hardness range for commercially grown CWAD lots of variable HVK was too narrow to allow meaningful segregation by NIRS particle size index.

The single-kernel characterization system (SKCS), which determines wheat moisture content, kernel weight, kernel diameter and hardness on individual kernels, was developed in the United States to aid in classifying hard and soft common wheat (Martin et al. 1993). The SKCS can analyze 300 kernels in about 3 minutes, and the extreme hardness of durum wheat compared to most common wheat classes makes SKCS potentially useful for determining adulteration of durum wheat by common wheat (Williams 2000b), and for determining HVK in durum wheat (Sissons et al. 2000).

Table 1. Relationship of durum wheat Single Kernel Characterization System (SKCS) hardness index to hard vitreous kernel (HVK) content for Canada Western Amber Durum wheat[1].

	SKCS Hardness Index		
HVK, %	Mean	Range	Standard Deviation
40	88.3	82.0 to 92.2	2.7
50	92.2	88.4 to 96.9	2.6
60	94.1	90.2 to 98.2	2.3
70	93.9	90.9 to 97.5	2.2
80	96.0	91.7 to 100.5	2.0
90	97.5	96.1 to 100.1	1.4

[1] Ten rail carlots with an HVK range of less than 1% were measured at each HVK value. Data taken from Symons and Dexter (2001).

Calibration equations have been developed with the SKCS to predict common wheat milling yield (Satumbaga et al. 1995). Sissons et al. (2000) were not able develop sufficiently strong relationships between SKCS data and durum wheat semolina yield to be useful for prediction purposes. However, they reported that HVK was strongly correlated to SKCS hardness index. Some caution is warranted because their sample set was artificially prepared by blending non-vitreous kernels in various amounts to a fully vitreous base sample. Fully starchy kernels are significantly softer than vitreous durum wheat kernels, but partially vitreous (piebald) kernels, which are considered non-vitreous, are almost as hard as fully vitreous kernels (Dexter et al. 1989). Piebald kernels commonly make up a large proportion of non-vitreous kernels, explaining why, as mentioned earlier, NIRS particle size index was unable to predict CWAD HVK or semolina milling yield (Dexter et al 1988). Recent work in our laboratory (Symons et al. 2001) using individual rail car shipments of CWAD indicates that SKCS hardness index is of limited value in predicting HVK (Table 1). There is a wide hardness range within rail carlots of comparable HVK, and there is overlap of hardness index values between samples differing widely in HVK.

Image analysis, or machine vision, has promise as a rapid aid to wheat grading and classification. Image analysis classifies kernels on the basis of size, shape and texture. Attempts to use image analysis for variety identification have been disappointing. It appears there is insufficient genetic diversity to differentiate kernel features for some cultivars, and environment has a strong influence on kernel size and shape (Keefe 1992; Myers and Edsall 1989).

Machine vision does have enormous potential for assessing wheat physical condition. Sapirstein and Kohler (1995 and 1999) concluded that the ability of machine vision to detect differences in kernel features among grades of Canadian wheat demonstrated potential to objectively classify wheat according to grade. Troccoli and di Fonzo (1999) found a strong relationship between kernel size features and test weight in durum wheat.

An application of machine vision of particular interest to durum wheat millers is the estimation of HVK (Sapirstein and Bushuk 1989; Shadadal et al. 1998; Symons et al. 2001). The methods are based on the relative translucency of vitreous and non-vitreous durum wheat kernels. The procedure of Symons et al. (2001) classifies individual kernels according to degree of vitreousness, which allows a percentage HVK to be computed. Results on bulked car lot samples and export cargoes agree reasonably well with Canadian Grain Commission visual HVK values, particularly when visual HVK values exceed 70% (Figure 1).

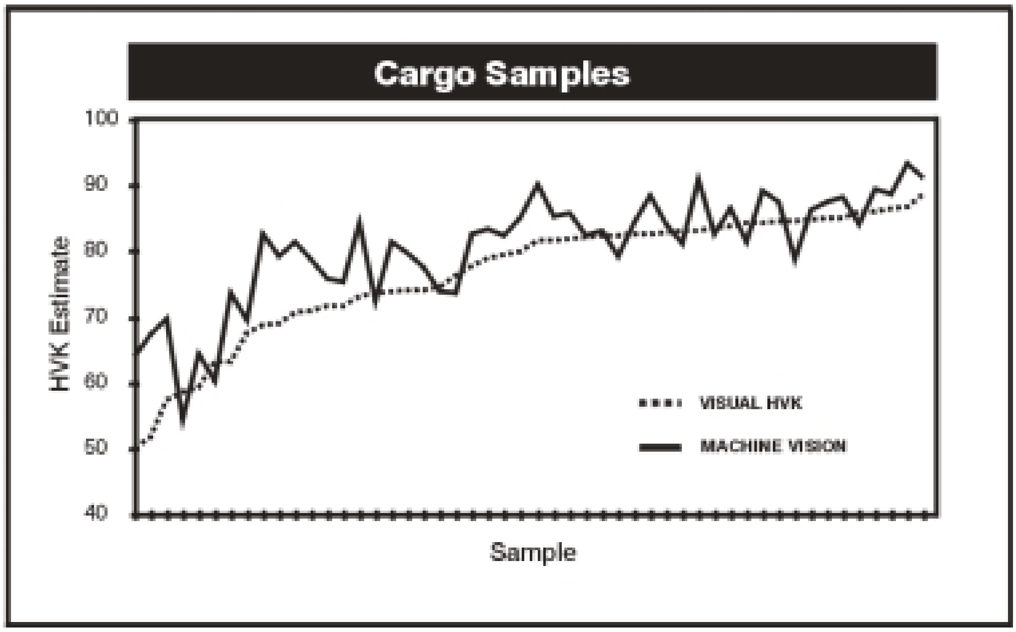

Figure 1. Comparison of Grain Research Laboratory machine vision hard vitreous kernel estimates (solid line) to Canadian Grain Commission visual inspection results (dotted line) for export cargoes of Canada Western Amber Durum wheat.

Surface discolourations, which cause undesirable dark specks in semolina and pasta, are of major importance in durum wheat grading (Dexter and Edwards 1998b). Machine vision systems that can rapidly and objectively measure surface discoloration should be possible. Luo et al. (1999) reported a colour machine vision system that classified healthy, broken, mildewed, grass green and frosted, black point and smudged, and heated kernels with over 90% accuracy. Ruan et al (1998) and Kokko et al. (1999) have reported machine vision systems that agree well with visual grain inspection values for *Fusarium* damage. Machine vision grading instruments, such as the Maztech SPY Grain Grader (Maztech MicroVision, Canada) are becoming commercially available.

In Canada a visual system, known as kernel visual distinguishability (KVD), has been used successfully for many years to keep wheat classes separate. Each wheat class has a unique kernel size, colour, and shape. The system works because Canada has a strict variety registration system that requires that varieties conform to the prescribed kernel features for its class, and that only superior quality lines may be registered (Dexter 1993). But KVD comes with a price, placing some limitation on the efforts of wheat breeders to develop improved varieties. The KVD system is under pressure due to the proliferation of wheat classes grown in Canada, and increasing demands for varieties with specific quality attributes for niche markets (Williams 1999). For example, extra-strong gluten durum varieties were registered in Canada in 1999 for test marketing (Clarke et al. 2000a and 2000b) even though they are not visually distinguishable from conventional strength CWAD varieties. The extra-strong variety AC Navigator, which became available in commercial quantities following the 2000 harvest, is being segregated from conventional CWAD varieties through an identity preserved system, to allow marketing on a variety specific basis. Accordingly, development of rapid variety identification methods to facilitate and monitor purity of specific segregations is a major research emphasis in Canada.

Separation of wheat storage protein by electrophoresis (Tkachuk and Mellish 1980) and reversed-phase high-performance liquid chromatography (Marchylo et al. 1988 and 1992) are well established and effective methods of determining variety composition. Capillary electrophoresis (Bietz and Schmalzried 1995) and matrix-assisted laser desorption/ionization mass spectrometry (Dworshak et al. 1998) have also been touted as procedures for variety identification. However, they are too costly, slow and complex to be used in a high throughput grain handling facility.

The analysis of wheat cultivars at the DNA level provides a potentially powerful method of identifying plant cultivars (Preston et al. 1999). Ko et al. (1994) found that polymerase chain reaction (PCR) can distinguish wheat cultivars, although caution must be applied with regard to genetic consistency of individual plants within a cultivar. PCR-based methods have great potential for detecting admixtures, and to prevent errors in handling grain in storage. Much of the procedure is suitable for automation, giving promise for rapid quantification of variety composition at low cost. Bryan et al. (1998) have reported a PCR-based method that can detect common wheat adulteration in durum wheat and pasta.

According to Williams (1999 and 2000a) electronic grading and classification is an inevitable development. Tremendous progress has been made in the past ten years. Rapid objective grading and classification will facilitate efficient segregation of classes and grades, identity preservation (IP) of varieties, and IP according to specific quality traits. The first challenge will be to apply this new technology to source wheat of appropriate quality grown over a wide area in western Canada. This potentially could take place at the farm level, since western Canadian farmers have sufficient storage capacity to store their complete harvest. Subsequently, grain of like quality must be gathered, binned together and moved though a grain handling system that has wheat storage capacity limitations. Extra cost will be associated with IP, for both seller and buyer, depending on how stringent the requirements are that are placed on the IP system. Additional cost will be associated with verification of variety and/or quality of the IP grain as it moves through the grain handling system to the point of export. The ultimate goal of such a system will be to provide more precisely the wheat characteristics (variety, yellow pigment content, semolina milling performance, gluten strength, etc.), that durum wheat millers and pasta manufacturers request. Ultimately the buyer will determine if the extra cost associated with obtaining wheat of more exacting quality is recoverable from customers.

SEMOLINA MILLING

Debranning prior to milling (preprocessing)

Considerable interest in the milling industry was aroused by reports that debranning (also referred to as preprocessing or pearling) of wheat prior to roller milling improved durum wheat semolina milling performance (Dexter et al. 1994a and 1994b), and generated by-products with unique functional and nutritional properties, (Dexter and Wood 1996). Evidence for improvement of common wheat milling performance is less conclusive (Dexter et al. 1994c).

There are two different commercial wheat debranning systems, the Tkac (1992) procedure and the 'PeriTec' process, marketed by Satake Corporation (McGee 1995). In both processes the wheat bran layers are removed by successive passages through modified rice polishers. A short conditioning period (3 to 5 min) is used to ensure that water penetrates into the outer regions only of the seed coat. Abrasion is used first in the Satake process, followed by friction, as in rice polishing. In the Tkac system the outer layers are removed first by friction passages followed by abrasion passages.

Recently developed wheat debranning equipment has a vertical configuration rather than the horizontal configuration traditionally used in rice polishing (Figure 2). In friction passages, as wheat kernels pass through the machine, the rotation of a vaned hollow shaft causes kernels to rub against each other. Introduction of air through vent holes in the shaft encourages the removal of friction by-products through an outer screen. In abrasion passages (Figure 2) kernels rub against an abrasive stone. Internal air pressure assists the removal of by-products through a screen. The most recent Satake debranning models combine successive abrasion and friction passages within one machine.

Table 2. Yield and composition of durum wheat before and after debranning, and of by-products produced during pilot-scale debranning using the Tkac process[1].

	Wheat		By-Products				
Property	UP	DB	F1	F2	A1	A2	A3
Yield, %	100	87.1	4.8	1.4	2.3	2.4	2.0
Ash, %	1.62	1.03	3.99	4.83	6.57	6.16	5.48
Protein, %	12.0	11.6	10.4	13.1	17.1	17.0	16.1
Lysine, mol%	2.6	2.2	4.2	4.8	4.3	4.4	3.9
β-Glucan, %	0.41	0.36	0.73	0.77	1.29	1.18	1.68
Fibre, %							
Insoluble, %	8.2	3.5	53.0	52.0	29.0	24.0	19.2
Soluble, %	2.7	1.9	2.7	2.3	3.7	4.1	4.2

[1] Data taken from Dexter and Wood (1996). UP = unprocessed; DB = debranned; F1 and F2 friction by-products; A1, A2 and A3 = abrasion by-products.

The Tkac system allows removal of each successive seed coat layer as separate by-products. These by-products have very interesting functional and nutritional properties. Their properties give them potential as novel food ingredients of higher value than by-products from traditional wheat milling. The friction products, which are primarily pericarp, contain high levels of dietary fibre (Table 2). The abrasion products, which are rich in aleurone, are enriched in protein, β-glucan and soluble fibre. Cui et al. (1999) reported that nonstarch polysaccharides extracted from Tkac abrasion by-products exhibited unique gelling properties.

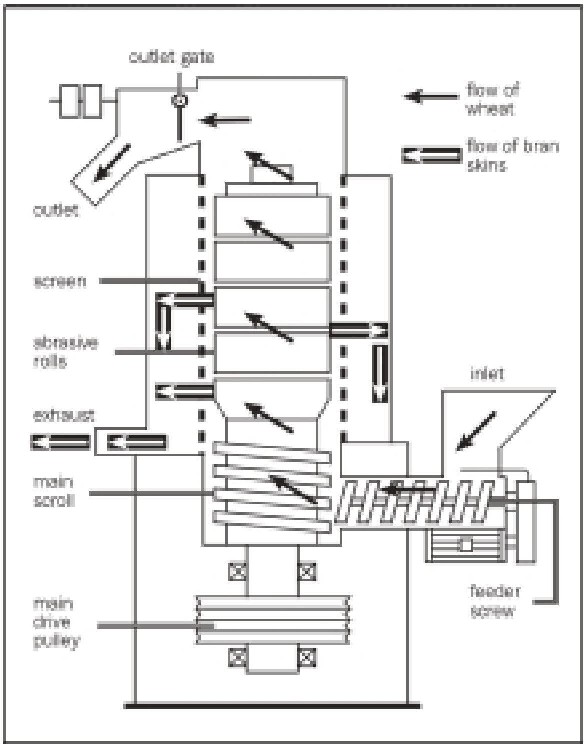

Figure 2. Schematic view of the internal flow of stock in the Satake VBW5A debranning machine

Using the Tkac system on a pilot-scale, Dexter et al. (1994a and 1994b) found that when diverse durum wheats were debranned under carefully controlled replicated experiments, the refinement of semolina as measured by ash, colour and number of bran specks improved (Table 3). The spaghetti from debranned wheat was slightly paler (lower purity), but that deficiency was more than offset by being brighter and less brown (shorter dominant wavelength). The improvement in pasta colour was readily detectable visually. Pasta cooking properties were not affected by debranning.

According to McGee (1995), commercial trials have shown that the PeriTec process also improves durum wheat milling performance, which has been confirmed by commercial millers who have adopted the process (proprietary communications). The number of grinding passes during milling is reduced because the bran coat is removed before milling, which increases the proportion of semolina compared to flour. A higher proportion of clean coarse semolina should offer some advantage when milling for couscous, where a coarse semolina is desirable. For best results, the settings for grinding rolls and purifiers must be optimized to allow for the greater release of semolina. The millflow is greatly simplified, offering the benefits of reduced plant size for a given capacity, and better process control.

Debranning gives durum wheat millers the option of increasing extraction rate, or compromising on raw material quality, without sacrificing semolina refinement. Dexter et al.

(1994a) estimated that debranning offers approximately a 5% yield advantage over traditional semolina milling at comparable semolina ash and colour. Surface discolourations of durum wheat kernels are serious problems to semolina millers because they cause dark specks in semolina (Dexter and Edwards 1998b). They are removed by debranning, making them of much less consequence, greatly enhancing the appearance of semolina from lower grade durum.

Another acknowledged advantage of debranning is in processing sprouted wheat. Alpha-amylase, which is associated with surface stickiness and reduced firmness of pasta produced from severely sprouted durum wheat (Dexter et al. 1990), is more effectively removed by debranning than by conventional roller milling (Henry et al. 1987; Liu et al. 1986). As seen in Table 3, this results in higher falling number in semolina from debranned durum wheat. Peroxidases, which have been associated with enzymatic browning of pasta (Kobrehel et al. 1972) are also concentrated in the outer layers (Fraignier 2000), and should be removed more effectively by debranning than by traditional semolina milling, contributing to superior pasta brightness.

Table 3. Effect of the Tkac debranning procedure on the properties of semolina and spaghetti from Canada Western Amber durum wheat[1].

	No 1 CWAD		No 3 CWAD	
Property	UP	DB	UP	DB
Semolina:				
Yield[2], %	64.2	65.7	63.7	64.0
Protein, %	11.5	11.4	13.1	13.1
Ash, %	0.69	0.58	0.71	0.63
Agtron colour, %	75	77	66	70
Specks per 50 cm^2	39	27	27	13
Falling number, s	645	685	185	245
Spaghetti:				
Colour:				
Brightness, %	51.6	52.0	48.9	49.2
Purity, %	42.5	39.1	41.6	41.0
Dominant wavelength, nm	576.6	576.2	576.7	576.6
Cooking quality				
Cooking score, units	52	56	70	55
Cooking loss, %	5.2	5.5	6.7	7.3

[1] Data taken from Dexter et al. (1994a).

[2] Semolina yield of debranned wheat adjusted to basis of wheat before debranning.

On-line and in-laboratory process control

NIRS is well established as a rapid and flexible technique for quality control in mill laboratories (Williams et al. 1981). NIRS also can be used on-line in a mill to monitor flour or semolina protein content and moisture content (Nelstrop 1987). On-line monitoring allows the miller to closely target protein and moisture content targets, improving efficiency. There is usually a premium associated with high protein durum wheat. Millers can get the most efficient use of wheat protein if semolina protein is maintained at or near the minimum specified. NIRS also can be used for determining ash content on-line in flour mills (Posner and Wetzel 1986), but this can be more problematic in semolina milling because diverse particle size of semolina streams affects reflectance spectroscopy calibrations.

Whitworth (1994) has described an image processing technique that can quantify the degree of bran contamination and measure the number of bran specks in flour on-line. The technology is applicable to monitoring bran speck counts during semolina milling. The apparatus has become commercially available as Branscan (Parascan Technologies, UK, Unit 8, Padgets Lane, South Moors Moat Ind. Est., Redditch, Worcs., B98 0RA). The Branscan system is designed to be inserted into a standard mill pipe, and uses a non-contact presentation mechanism to obtain milled product (final blended product, or a stream from earlier in the milling process), and can have up to eight measurement stations. Branscan provides a very useful early warning signal if there is a problem in the mill, allowing troubleshooting almost immediately before large amounts of poor quality products are produced.

Image analysis has enormous potential for product control, and practical applications are being developed and commercialized. Fluorescence imaging can be used to quantify the amount of aleurone and pericarp in flour (Jensen et al. 1982). Symons and Dexter (1996) found that pericarp fluorescence was strongly related to ash content and colour for diverse streams from Canada Western Amber Durum wheat. A bench-top instrument was commercialized by Dipix Technologies in Canada (Harrigan 1995), and the technology is now available from Maztech MicroVision, Canada (1051 Baxter Road, Unit 21, Ottawa, ON, K2C 3P1).

Table 4. Comparison of visual speck counts and Maztech SPX Speck Expert counts at three speck size settings[1].

Sample	Particle size minimum, μm	Manual black specks, specks/cm^2	Maztech black specks, specks/cm^2	Manual brown specks, specks/cm^2	Maztech brown specks, specks/cm^2
A	168	0.01	0.15	0.31	0.32
	156		0.15		0.41
	142		0.15		0.47
B	168	0.03	0.12	0.25	0.26
	156		0.12		0.31
	142		0.11		0.38
C	168	0.02	0.09	0.17	0.19
	156		0.08		0.25
	142		0.07		0.28

[1] Data taken from Harrigan and Bussmann (1995).

Speck counting is universally used in durum wheat mill laboratories to monitor semolina quality, and to meet customer specifications. Visual speck counting is tedious and notoriously subjective. Image analysis provides a rapid objective option to visual counting (Symons et al. 1996; Novaro et al. 2000). Harrigan and Bussman (1998) reported on a commercially available instrument from a Canadian company, Maztech MicroVision. The imaging system differentiates between black and brown specks, and can be calibrated to agree with visual counts by setting the machine to recognize only specks over a specified minimum size (Table 4). A Maztech SPX Speck Expert is in use in our laboratory, and it gives reliable counts for brown and black specks. Branscan also offer a bench-top speck counter in addition to the on-line system described above.

Colour measurement of pasta using a colorimeter to determine chromaticity values (*L*a*b**) has become common practice because of the development of flexible, reliable and affordable computer assisted hand-held instruments. Chromaticity values provide objective measurements of pasta brightness and hue, but they do not provide a means of quantifying or characterizing the visual impact that dark specks and other surface flaws may have on consumer acceptance. Hatcher et al. (1999) have developed a computer imaging system that can detect, quantify and characterize regions of undesirable colour (i.e. specks) on or below the surface of Asian noodles. It should be possible to develop a similar system to characterize pasta.

Finer Granulation and Higher Extraction Rate

In recent years engineering innovations have developed presses with much greater capacity and improved performance. Associated with their introduction there has been a move to finer semolina granulation to accommodate increased mixing speeds and reduced mixing time, and to improve homogeneity of the extruded dough. For example, in 1995 Bühler introduced the Polymatik press, that uses a twin-screw mixer/kneader system to mix and develop dough in 20 seconds.

To produce semolina with finer granulation, mills have a semolina reduction plant (Bizzarri and Morelli 1988). Regrinding semolina has a number of negative implications on pasta quality. Reducing semolina greatly increases starch damage because durum wheat is so hard (Resmini et al. 1996). Consequently, when low temperature drying (LT) is used in pasta-making, increased starch damage results in higher loss of solids during cooking (Figure 3), and more surface breakdown, leading to stickiness (Matsuo and Dexter 1980).

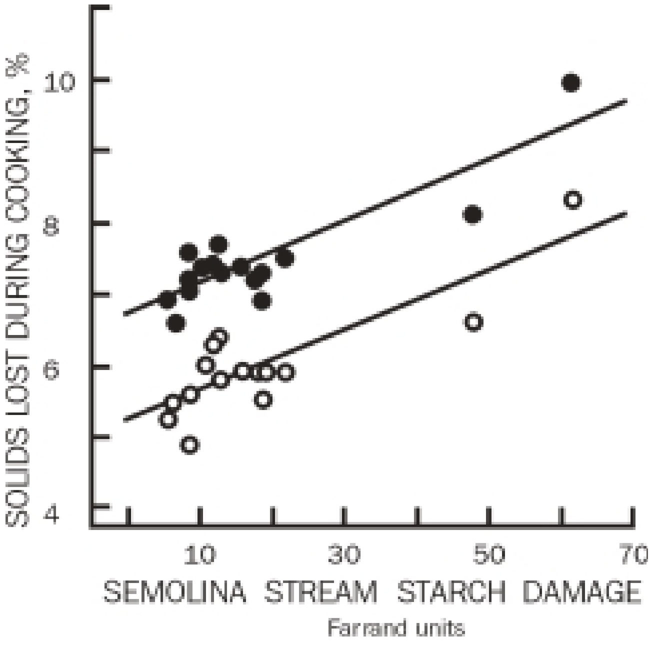

Figure 3. Relationship of semolina starch damage to solids lost to cooking water for pasta cooked to optimum time (O) and overcooked (●). (Data taken from Matsuo and Dexter 1980).

High cooking loss and poor surface characteristics associated with high starch damage in semolina are overcome by high temperature (HT) drying (Dexter et al. 1981a and 1983). However, under HT conditions other problems emerge associated with pasta colour and nutritional properties. HT drying (temperature over 60^{o}C) favours nonenzymatic browning due to Maillard reaction (Pagani et al. 1992). The Maillard reaction occurs when carbonyl groups, usually reducing sugars, condense with free amino groups from amino acids, peptides and proteins (Sensidoni et al. 1999).

The initial stage of the Maillard reaction occurs without influencing pasta colour, but significant loss of the essential amino acid lysine can occur (Dexter et al. 1984). Pagani et al. (1992) found that the first stage of Maillard reaction is favoured during HT drying at low pasta moisture (<16%), a result confirmed by Resmini et al. (1996). High starch damage results in higher reducing sugar content in semolina. Elevated reducing sugar content, in combination with HT when pasta moisture is low, can result in advanced Maillard reaction. The pasta becomes undesirably red, which affects marketability. Nutritional properties are affected, not only by loss of nutritional value of protein, but also due to formation of unnatural compounds, the safety of which is dubious and still under investigation (Resmini et al. 1996).

Starch damage can be minimized by milling directly for finer granulation without regrinding. This approach requires a longer conditioning time to fully mellow the endosperm. Purification remains the heart of the process, but the main product comes from sifters following secondary purification. The main implication on pasta quality is the tendency for loss of pigment during the long conditioning period (A. Sarkar, personal communication, Canadian International Grains Institute, Winnipeg). Steam treatment prior to conditioning, which is well known to reduce lipoxygenase activity, may help limit bleaching during conditioning and further processing (Irvine et al. 1967).

Economic pressures are forcing millers to increase extraction rates in some markets, especially in South America. This, of course, has major effects on pasta colour. The main oxidative enzyme associated with pigment loss, lipoxygenase, is concentrated in germ (Bhirud and Sosulski 1993), and enzymes associated with browning, peroxidase and polyphenol oxidase, are concentrated in outer regions of the seed coat (Fraignier et al. 2000; Hatcher and Kruger 1993). As a result, as extraction rate increases oxidative enzyme levels in semolina increase, pigment loss during pasta processing increases, and pasta becomes increasingly dull and brown (Matsuo and Dexter 1980) (Figure 4). Low-grade semolina streams also tend to be higher in starch damage and in alpha-amylase, resulting in increased reducing sugar content, which exacerbates nonenzymatic browning (Resmini et al. 1996).

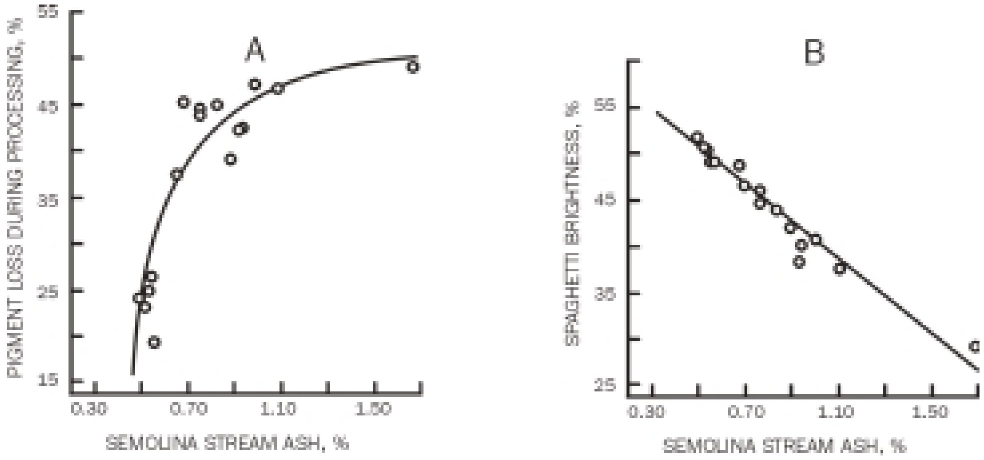

Figure 4. Relationship of semolina ash content to A, pigment loss during pasta processing and B, pasta brightness.

Trends to finer granulation and higher extraction rate have several potential impacts on durum wheat quality. The trend to finer granulation may make the effect of HVK on durum wheat hardness of less consequence, lessening its importance as a quality specification for durum wheat trade. HVK also negatively impacts on protein content (Dexter et al. 1989), but that factor is of no consequence if a minimum protein content is specified. The trend to higher extraction rates will put greater emphasis on improving the intrinsic colour properties of durum wheat varieties, with particular emphasis on increasing yellow pigment content up to the maximum limit of consumer acceptance, and minimizing oxidative enzyme activity.

PASTA PROCESSING

High temperature and ultra-high temperature drying: Impact on durum wheat quality criteria

The dramatic change in pasta drying technology during the later part of the 20th century has had a profound effect on raw material standards. First came the introduction of HT drying (60^{o}C to 85^{o}C) (Manser 1980; Pavan 1979). HT drying was rapidly accepted by the pasta-making industry because of improved hygeine and improved cooking quality, compared to LT drying. Now ultra-high temperature (UHT) drying (85^{o}C to 110^{o}C) has become common, with drying times as short as ~ 4-5 hr for long goods and ~ 2-3 hr for short goods (Pollini 1996).

HT and UHT technology has allowed the production of pasta with acceptable, or even superior cooking quality, from mediocre quality raw material (Malcolmson et al. 1993). Protein content has long been recognized as the primary factor associated with superior pasta texture (Dexter and Matsuo 1977). There is no doubt that protein content remains a primary determinant for superior pasta cooking quality under HT conditions.

Gluten strength has been widely reported as an important secondary prerequisite for superior pasta cooking quality (Autran et al. 1986; Dexter and Matsuo 1980; Kovacs et al. 1997; Mariani et al. 1995; Matsuo et al. 1982). However, the relationship between gluten strength and pasta cooking quality is complex, and somewhat controversial. According to Matsuo (1993) gluten strength does not guarantee superior pasta cooking quality. Durum wheat gluten strength and physical dough properties are highly heritable, but environment strongly influences pasta texture (Ames et al. 1999; Autran et al. 1986; Matsuo et al 1982). Further, there is strong scientific evidence that under HT and UHT drying conditions, gluten strength has less influence on pasta cooking quality than under LT drying conditions (D’Egidio et al. 1990 and 1996; Schlichting et al. 2001). Marchylo et al. (2001), confirmed that for Canadian durum wheat breeding lines, genotype contributed less to HT cooking quality variance than to LT cooking quality variance.

Regardless of whether gluten strength might be overestimated as a cooking quality prerequisite, particularly for pasta dried at HT, there has been increasing emphasis placed on strength as a durum wheat quality specification (Marchylo et al. 1998). This can be attributed to the emergence of the sodium dodecyl sulphate sedimentation test (Dexter et al. 1980; Quick and Donnelly 1980) and the gluten index test (Cubadda et al. 1992). Both are simple methods to differentiate durum wheat gluten strength. D’Egidio et al. (1990) have shown that the alveograph is an excellent indicator of durum wheat gluten properties, and alveograph parameters have become important specifications for Italian processors.

In general, studies that have identified gluten strength as an important prerequisite for good cooked pasta texture have included very weak gamma-gliadin-42 lines, which clearly exhibit inferior pasta texture. Gamma-gliadin-45 types, which are well known to be of superior cooking quality to gamma-42 types (Damidaux et al. 1978; Kosmolak et al. 1980), have a strength rank from moderately strong and extensible to extraordinarily strong and inextensible (Edwards et al. 2001; Rao et al. 2001). Regardless of strength, gamma-gliadin 45 types are genetically linked to low molecular weight glutenin subunits identified as LMW-2. These subunits are controlled at the *Glu-B3* locus (Payne et al. (1984) and are believed to be the causal effect for superior pasta cooking quality (Pogna et al. 1988).

In Canada screening for gamma-45 gliadin types is performed early in the breeding program (Clarke et al. 1993). As a result all lines in the Canadian breeding program, and all recently released varieties, regardless of strength, are gamma-45 types. In Table 5, the old varieties Wascana, released in 1971 (Hurd et al. 1972), and Stewart 63, released in 1963, are gamma-gliadin-42 types (Kosmolak et al. 1980). According to the gluten index and alveograph Wascana is stronger than Stewart 63, and this is reflected by superior pasta texture. The other four varieties, all released within the past 5 years are gamma-45 types, and all exhibit superior cooking quality to Wascana. However, AC Pathfinder and AC Navigator, which are very strong, exhibit comparable cooking quality to the intermediate strength varieties AC Avonlea and AC Morse, respectively, at comparable protein content.

Table 5. Strength characteristics, pasta texture and baking quality of some Canadian durum wheat cultivars[1].

Property	AC Pathfinder	AC Navigator	AC Morse	AC Avonlea	Wascana	Stewart63
Semolina:						
Protein, %	11.9	12.0	12.0	12.8	12.2	12.0
Gluten index, %	87	89	62	38	40	27
Alveograph:						
P/L	1.6	2.0	0.8	0.5	0.5	0.5
W	301	268	179	145	80	49
70°C Spaghetti						
Optimum time						
Peak force, g	393	406	422	430	378	318
Overcooked 5 min						
Peak force, g	336	344	341	345	310	247
CSP bread						
Mix time, min	10.0	10.2	7.9	7.3	5.5	3.3
Loaf volume, cc	875	820	830	795	760	680
Remix bread						
Remix time, min	3.3	2.4	2.3	2.0	1.3	0.5
Loaf volume, cc	715	610	610	550	470	390

[1] Data taken from Rao et al (2001).

Edwards et al. (2001) examined the viscoelastic properties of durum wheat semolina doughs of different strengths. They concluded from creep behavior that high steady state viscosites of strong durum doughs and relative inextensibility (low compliance) was consistent with strength in durum wheat being primarily a function of the density of physical crosslinks present. Weaker durum wheat varieties have a higher proportion of gliadins (Edwards et al 2001; Rao et al 2001), which would not be expected to participate in intermolecular cross-links, and may also prevent formation of sufficient cross-links/unit volume to achieve desirable solid-like behavior in cooked pasta. Once a critical number of cross-links is achieved, as for moderately strong varieties like AC Avonlea and AC Morse, there would be little or no advantage to cooked pasta firmness in having more cross-links.

Colour has always been an important aesthetic factor associated with consumer choice in pasta. Increased competition has made colour even more important. This is true even in Italy, where colour has traditionally been secondary to texture. The pasta industry is becoming more global in nature, and quality criteria are becoming more demanding. With globalization has come fierce competition that has made it more important for pasta processors in markets that have traditionally not been quality conscious to produce a better product, and one that is consistent over time. Consumers have responded by becoming more discriminating and less tolerant of variability in product quality.

Acquisition of modern technology virtually assures pasta manufacturers of producing a good product. Aside from the danger of increased Maillard reaction during HT and UHT drying, improvements in drying cycles and press technology, and computer control, have improved pasta quality. The Polymatik press described earlier offers particularly good colour. Vacuum is applied immediately, and dough is into the extruder within 20 s, greatly reducing the opportunity for pigment loss during processing.

Canadian response to changing quality demands

The Canadian durum wheat industry is particularly sensitive to changing quality demands because up to 70% of Canadian durum wheat production is exported (Dexter and Marchylo 1997; Marchylo et al. 1998). Canada is currently reevaluating the strength and colour quality models for Canada Western Amber Durum (CWAD) wheat (Marchylo and Dexter 1996). The variety Hercules has been the minimum quality standard for CWAD since 1971 (Dexter and Marchylo 1997). Hercules had improved colour and gluten strength over previous Canadian durum wheat varieties when it was first released (Leisle 1970). The Hercules quality model has served Canada well. Durum wheat production in Canada has increased from about 0.5 million MT annually in the 1960's to about 5.5 million MT in 2000.

Table 6. Quality data for some Canadian amber durum wheat cultivars[1,2].

Variety	WPR %	SDS ML	GI %	APL	AW J x 10^{-4}	70b*	90b*	70CS units	90CS units
Hercules Model									
Hercules	14.0	55	40	0.19	109	66.1	67.9	28	43
Kyle	13.8	43	22	0.31	90	68.2	68.3	29	48
AC Avonlea	14.5	50	40	0.34	114	69.4	69.0	45	57
IS Model									
AC Morse	14.4	60	62	0.48	177	67.9	69.0	40	58
DT 494	14.1	55	62	0.39	140	72.8	72.8	40	53
ES Model									
AC Pathfinder	13.6	74	93	0.67	260	68.0	69.1	39	49
AC Navigator	13.7	63	86	0.71	192	74.1	74.2	45	52

[1] Data taken from the 1999 Prairie Registration Recommending Committee for Grain Wheat Rye and Triticale Subcommittee report.

[2] WPR = wheat protein content; SDS = SDS-sedimentation volume; GI = gluten index; APL = alveograph P/L; AW = alveograph W; 70b* and 90b* = b* of spaghetti dried at 70°C and

90°C; 70CS and 90CS = cooking score of 70°C and 90°C dried spaghetti; IS = intermediate strength; ES = extra strong.

In response to changing market demands, Canada has released several new varieties eligible for CWAD grades that have better colour and stronger gluten than Hercules (Marchylo and Dexter 1996). In 1999 two varieties with very strong gluten, AC Pathfinder and AC Navigator were granted interim registration for test marketing as Extra-Strong (ES) CWAD (Clarke et al. 2000a and 2000b).

The direction of the Canadian durum wheat breeding program is apparent from quality data of breeding lines from Canadian durum wheat breeding trials in 1999 (Table 6). Kyle, which was registered in 1984 (Townley-Smith et al. 1987) and is currently over 70% of Canadian production, is comparable in protein content and gluten strength to Hercules, by sodium dodecyl sulfate (SDS) sedimentation, gluten index (GI), and alveograph P/L (APL) and W (AW) values. AC Avonlea, registered in 1997 (Clarke et al. 1998), has Hercules-type strength, but improved wheat protein content, and has consistently exhibited superior pasta cooking quality. AC Avonlea also has improved pasta yellowness as indicated by higher b* values for spaghetti dried at 70°C and 90°C. AC Morse, registered in 1996, and DT 494, supported for registration in 1999, are typical of the new CWAD quality model. DT 494 exhibits much improved pasta yellowness. AC Morse and DT 494 both exhibit significantly stronger gluten properties than the Hercules model. AC Navigator and AC Pathfinder, registered for test marketing as ES-CWAD, exhibit a further incremental increase in gluten strength, as evident from much higher SDS, GI, APL and AW. AC Navigator has the added advantage of superior pasta yellowness.

The future direction of the CWAD breeding program will be determined by dialogue with users of Canadian durum wheat. Indications are that improved pasta colour over Kyle is widely appreciated. In some markets AC Navigator and DT 494 may have the maximum acceptable yellowness because of concern that consumers may associate very intense yellowness in pasta with artificial colouring. The additional strength of AC Morse and DT 494 is universally appreciated. Test marketing of AC Navigator, in particular, has met with positive response in some markets, whereas others have expressed a preference for more conventional CWAD strength. For example, dough extensibility is required for production of fresh pasta, which is usually sheeted.

An advantage of the extra strength of AC Pathfinder and AC Navigator, is that in blends with weak low protein varieties, gluten strength and pasta texture are improved more than in blends with moderately strong durum varieties (Schlichting et al. unpublished). Until clear market preference is established, for the next few years at least, the ES-CWAD varieties will be identity preserved and marketed separately from the conventional varieties comprising the CWAD wheat class.

BREAD-MAKING

Durum wheat has found traditional use in flat breads and specialty breads, particularly in Mediterranean countries (Quaglia 1988). Durum bread has a yellowish colour, a characteristic taste and smell, a fine and uniform crumb structure, and more prolonged shelf-life, all of which appeal to some customers (Liu et al 1996). Durum wheat utilisation in Mediterranean regions is increasing. According to Palumbo et al. (2000) in Italy in the last 10 years the share of durum wheat used for bread-making has increased from 4% to 10% of Italian production.

There have been a number of studies related to the suitability of durum wheat for making high volume hearth bread and pan bread (Boggini et al. 1995; Boggini and Pogna 1989; Boyaçioglu and D'Appolonia 1994; Dexter et al. 1981b and 1994d; Hareland and Puhr 1999; Josephides et al. 1987; Lopez-Ahumada et al. 1991; Peña et al. 1994; Quick and Crawford 1983). In summary, it has been reported that durum wheat baking performance improves as gluten becomes stronger, but loaf volumes achieved for the best performing durum wheat cultivars are substantially lower than for bread wheat. Many studies acknowledged the inferior baking potential of durum wheat, and focused on improving baking performance by blending durum wheat with common wheat.

Despite low loaf volume, durum wheat bread crumb properties are good, and it has been reported that durum wheat bread stales less quickly than common wheat bread (Quaglia 1988). Very strong gluten durum has baking limitations, attributed to tenacious gluten, which imparts inextensible dough (Ammar et al., 2000; Edwards et al. 2001; Quaglia, 1988; Rao et al. 2001).

There is considerable interest in developing durum wheat suitable for both bread-making and pasta-making (Liu et al 1996). Dual-purpose durum wheat is a desirable goal because such cultivars would have alternative markets in years of high production, and could be used in place of bread wheats either alone or in blends with high quality baking flour (Boggini and Pogna 1989).

As discussed earlier there has been a move towards stronger gluten in the Canadian breeding program. In view of increasing interest in durum wheat for bread, Marchylo et al (2001) initiated an investigation to determine whether stronger lines in the Canadian breeding program have improved baking performance. When baked by the Canadian short process, a mechanical development process similar to that used in many Canadian bakeries, the strongest lines exhibited mixing times and mixing energies similar to or greater than good quality bread wheat. Durum wheat loaf volume was positively related to gluten strength, but the strongest lines still exhibited only about 85% of the loaf volume expected of good quality bread wheat. Baking quality was not related to pasta cooking quality, confirming that there is potential to breed dual-purpose durum wheat varieties which combine improved baking properties and good pasta cooking quality.

Durum wheat gluten strength is a much more obvious advantage for longer fermentation time baking methods like the remix process (Dexter et al. 1998). As seen from the data of Rao et al. (2001) in Table 5, gluten strength was an asset in determining short process loaf volume, but the moderate strength cultivars performed almost as well as the strongest ones. When baked by the remix process, the weaker cultivars show a greater loss of loaf volume than the stronger cultivars.

Palumbo et al. (2000) examined the bread-making quality of durum wheat genotypes derived from crosses with bread wheat to transfer HMW glutenins encoded by *Glu-A1*, usually absent in most durum wheat cultivars. They did not observe any improvement in baking performance. There have been reports of a relationship between bread-making quality and allelic variation in *Glu-B1* for Italian (Boggini et al. 1998; Boggini and Pogna 1989) and Mexican (Peña et al. 1994) durum genotypes. However, Ammar et al. (2000) noted conflicting conclusions as to which *Glu-B1* allele is associated with better baking performance, suggesting that bread-making quality is dependent on the set of genotypes evaluated. The type of baking process used (i.e. long or short fermentation) would also influence conclusions.

Genetically, durum wheats are tetraploids (AABB), and lack the D genome found in hexaploid common wheats (AABBDD). Removal of the D genome greatly reduces its baking potential (Kerber and Tipples 1969) and is considered at least partly responsible for the relatively poor baking quality of durum wheat. Redaelli et al. (1997), working with common wheat near-isogenic lines, demonstrated that chromosome 1D strongly influenced both dough elasticity and extensibility.

As concluded by Ammar et al. (2000), to improve the baking quality of durum wheat, greater extensibility and greater dough strength is required. The most promising path to improve durum wheat baking quality might be incorporation of gluten proteins encoded by the D-genome. Ceoloni et al (1996) and Pogna et al (1996) have reported a positive effect on bread-making quality when LMW glutenin subunits encoded by the *Glu-D3* locus are translocated into durum genotypes. The question remains whether the acknowledged superiority of durum wheat pasta cooking quality over that of common wheat will be retained for durum wheat translocation lines.

QUESTIONS FOR THE FUTURE

There has been increasing demand by durum wheat millers and processors to source durum wheat shipments with specific quality attributes. In addition to physical specifications, this may involve specifications for minimum protein content, specific gluten strength and dough extensibility attributes, and colour. In some cases a durum wheat variety (or varieties) may be specified. Will rapid objective grading and classification methods become available to allow grain handling and classification systems to meet the challenge?

Preprocessing (debranning) of durum wheat before semolina milling appears to improve durum wheat milling extraction rate and semolina refinement (lower ash and fewer specks). Surface discolourations are removed by debranning making them of less importance in determining semolina refinement. Semolina falling number is improved. Is debranning likely to become the method of choice for durum wheat millers? If so, will it affect physical specifications for durum wheat, i.e., will there be more opportunity to market lower grade durum wheat for premium quality pasta?

Pasta equipment manufacturers are suggesting finer semolina granulations for modern high capacity presses and for Polymatik presses. Will hard vitreous kernel specifications, which are designed to guarantee hard kernel texture and ensure a high yield of coarse semolina, become of less importance? Finer granulation leads to higher starch damage, which increases the risk of Maillard reaction, particularly with HT and UHT drying. How will the inferior pasta colour and anti-nutritional implications of Maillard reaction affect semolina granulation and the use of HT and UHT drying?

There is increasing scientific evidence that gluten strength is of minimal importance in determining the cooking quality of HT and UHT pasta. Yet, gluten strength is becoming an increasingly important specification in some markets. Will gluten strength continue to be important in the future, or will pasta manufacturers focus more on guarantees of minimum protein content and guarantees of good colour?

Is the recent increase in interest in durum wheat baking the beginning of a long-term trend, or a passing fad? What are the prospects for developing dual-purpose durum wheat suitable for high quality bread and pasta? Is putting plant breeding resources into development of durum wheat lines with improved baking performance justified?

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