Preprocessing: Effects on Durum Wheat Milling and Spaghetti-Making Quality[1]

J. E. DEXTER,[2] D. G. MARTIN,[2] G. T. SADARANGANEY,[3] J. MICHAELIDES,[3]
N. MATHIESON,[3] J. J. TKAC,[4] and B. A. MARCHYLO[2]

Cereal Chem. 71(1):10–16

ABSTRACT

Three Canadian durum wheats were preprocessed according to the patented Tkac procedure, which involves the removal of bran layers by sequential friction and abrasion passages using modified rice polishers. The semolina-milling potential and the spaghetti-making quality of the preprocessed wheats were compared to those of the corresponding unprocessed wheats. For all wheats at comparable extraction rates, the ash content of semolina from the preprocessed wheats was much lower. The superior refinement of the semolina from preprocessed durum wheat was also evident by a higher Agtron color and reduced speckiness. The preprocessed durum wheats exhibited a significant semolina-milling yield advantage over the corresponding unprocessed wheats when milled to comparable degrees of refinement. Preprocessing had a beneficial effect on spaghetti brightness and brownness. Cooked spaghetti texture was not affected by preprocessing.

Wheat starchy endosperm constitutes over 80% of the wheat kernel (Bradbury et al 1956). However, complete separation of the starchy endosperm from other wheat tissues is never achieved during conventional roller milling. According to Zeigler and Greer (1971), wheat flour refinement begins to deteriorate at extraction rates beyond 65%, and beyond 75% extraction, the rate of deterioration accelerates.

The possibility that removal of the outer layers of the wheat kernel before milling might improve the yield and the refinement of flour has been the subject of numerous investigations (Pomeranz 1961). Grosh et al (1960) experimented with abrasive scouring (pearling) of wheat before milling. They found that the outer pericarp could be efficiently removed, but subsequent milling results were inferior to conventional milling results. Wasserman et al (1970, 1972) investigated the relative merits of debranning wheat by friction (rubbing of kernels against each other) using rice polishers and by abrasion using a barley pearler. They concluded that debranning of wheat by friction was practical only when a 5-min temper was employed, whereas efficient debranning by abrasion was practical without tempering. They presented no milling data for the debranned wheat.

There has been interest in abrasive debranning of sprouted wheat with barley pearlers to improve the falling number of sprouted wheat (Liu et al 1986, Henry et al 1987). Debranning effectively reduced wheat-amylase activity, but no improvement in wheat milling performance was demonstrated.

Recently, there has been renewed interest in debranning of wheat before milling as a means of improving wheat-milling performance (Satake 1990, Sugden 1991). Two U.S. patents were awarded for wheat debranning processes using modified rice pearlers (Tkac 1992, Wellman 1992). The Tkac system, in particular, has aroused considerable interest (Sugden 1991, McGee 1992, Timm 1992, Willm 1992). It involves preprocessing the wheat by removing bran layers during sequential friction and abrasion passages through modified rice polishers. The preprocessed wheat is then milled by conventional roller milling equipment. Proponents of the Tkac system cite increased return on millfeed due to the composition and functionality of some fractions derived from by-products of preprocessing, increased plant capacity, increased milling yield, improved flour refinement, and simplification of the mill flow.

Previous articles on the Tkac preprocessing system described commercial results in general terms and focused primarily on common wheat milling. In this investigation, we report the results of carefully controlled preprocessing experiments in which we investigated the effects of preprocessing on Canadian durum wheat properties, semolina-milling performance, and spaghetti-making properties.

MATERIALS AND METHODS

Wheat

All wheats were drawn from commercial channels. The No. 3 Canada Western Amber Durum (CWAD) wheat was from the 1990 Canadian harvest; the No. 1 CWAD wheat was from the 1991 harvest. The Ontario durum (cv. Edmore) was grown in southern Ontario in 1991. It was of poor quality. When examined by a Canadian Grain Commission grain inspector, it was judged to be of feed quality due to shrunken kernels and low test weight.

Preprocessing

In the preliminary phase of the study, the No. 3 CWAD wheat was preprocessed on a pilot scale at Robinson Milling Systems (RMS) (now Satake, UK) in Stockport, England, using a TrigoJet polishing machine described by McGee (1992). In the second phase of the study, the No. 1 CWAD and the Ontario durum were processed on a pilot scale at Refaccionaria de Molinos (REMO), Mexico City, using the Vertijet VJ III (REMO 1989).

Tkac preprocessing was previously described in detail (McGee 1992, Tkac 1992, Willm 1992). In the process, bran layers are removed during sequential friction and abrasion operations by a series of modified rice-polishing machines. About 65% of the bran is removed during the process. The remaining bran is confined to the crease area and is removed during conventional roller milling.

There were some limitations to our pilot-scale experiments. The resting time after tempering is critical to the effectiveness of preprocessing. The grain should lie in the holding bin for 3–5 min, the time required to penetrate the outer bran layers. Longer lying times result in fusion of the bran layers and less efficient separation of the bran layers during preprocessing. At RMS, a Technovator was available for tempering, so tempering was not a factor in the effectiveness of preprocessing. However, the precision and uniformity of temper water application at REMO was not ideal. Water was applied in a stream rather than a mist. Uniformity of water uptake was achieved by a long screw conveyor, which meant that the tempering time was longer than ideal. At both REMO and RMS, only one polishing machine was available, necessitating a lengthy interruption of the process after the friction passages to convert the machine for abrasion. The wheats were processed in relatively small batches (50–100 kg), so at each friction and abrasion stage the machines were not fully loaded for a significant period, and therefore not operating at full efficiency.

To precisely estimate the milling yield of the preprocessed wheat on an unprocessed wheat basis, it is essential to estimate accurately the amount of by-product removed during preprocessing. By-

[1]Presented in part at the AACC Pacific Rim Conference, March 1993, Honolulu, HI.

[2]Contribution 700 of the Canadian Grain Commission, Grain Research Laboratory, Winnipeg, MB.
[3]Robin Hood Multifoods, Rexdale, ON.
[4]Tkac and Timm Enterprises, Port Colborne, ON.

products could not be quantified at RMS. However, on the basis of past commercial experience, and the decrease in wheat kernel weight, the amount of by-product removed during preprocessing was estimated to be from 8–10% of the original wheat.

During the REMO pilot-scale trials, the amount of by-product removed at each stage was quantified. Representative samples of the wheats at each stage of preprocessing, and the corresponding by-products, were retained for analysis to confirm yield estimates.

Wheat Physical Properties

Test weights were determined with a Schopper chondrometer using a 1-L container (Dexter and Tipples 1987); kernel weights were determined as described by Dexter et al (1987).

Semolina Milling

Samples were commercially cleaned before preprocessing, so they were milled without further cleaning. All millings were performed in duplicate 2-kg lots, except for the high-extraction millings of the No. 3 CWAD wheats, which were performed singly due to limited sample.

Wheats were prepared for milling as described by Dexter and Tipples (1987). All unprocessed and preprocessed wheats were tempered to 16% moisture content overnight (16 hr), the standard Grain Research Laboratory procedure. In addition, the No. 3 CWAD unprocessed and preprocessed wheats were milled after tempering periods of 6 and 4 hr, respectively. Millings were performed with a four-stand Allis-Chalmers mill in conjunction with a laboratory purifier (Black 1966) according to the procedure of Dexter et al (1990). The No. 3 CWAD unprocessed and preprocessed wheats were also milled to higher extraction by adding an additional break passage, an additional sizing passage, and two additional purifications.

The yields of semolina and granulars (semolina and flour combined) were expressed as the proportion of clean wheat on a constant moisture basis. The yields of the preprocessed wheats were also adjusted to take into account material lost during preprocessing. Specks in semolina and granulars were estimated as described by Dexter and Matsuo (1982).

Analytical Tests

All analytical tests were performed in duplicate and are expressed on a 14% mb. The moisture contents of ground wheat, preprocessing by-products, semolina, and flour were determined with a rapid moisture tester (C. W. Brabender Instruments, South Hackensack, NJ) as outlined in the instruction manual.

The sodium dodecyl sulfate (SDS) sedimentation volume of wheat was determined by the modified method of Dexter et al (1980). The protein contents (% N × 5.7) of wheat, preprocessing by-products, semolina, and granulars were determined by the Kjeldahl procedure as modified by Williams (1973). Ash content, Agtron color, and wet gluten content were determined by AACC methods 08-01, 14-30, and 38-11 (AACC 1983).

Wheat falling numbers were determined on 7-g samples from duplicate 300-g grinds (Tipples 1971). The falling numbers of semolina and granulars were determined on duplicate 7-g samples. α-Amylase activities were determined by a nephelometric technique (Kruger and Tipples 1979), and polyphenol oxidase activities were determined by the method of Hatcher and Kruger (1993) on semolina and granulars and on the wheat falling number grinds.

Spaghetti Processing

Spaghetti was prepared by the microprocedure described by Matsuo et al (1972). Semolina and granulars from each replicate milling were processed in duplicate to allow drying once each by the 39 and 70°C drying programs described by Dexter et al (1981).

Spaghetti Color

Spaghetti color was determined with a spectrophotometer (DU-7, Beckman Instruments, Fullerton, CA) in duplicate on whole strands of spaghetti mounted on white cardboard (Daun 1978).

Spaghetti-Cooking Quality

Optimum cooking time was defined as the time required for the white strands to disappear, determined by crushing strands between transparent plates. Cooking tests were performed in duplicate on 10 g of spaghetti broken into 5-cm strands and cooked in 200 ml of boiling water. The cooking water was adjusted to a predetermined hardness (Dexter et al 1985) to eliminate the effect of variable hardness on cooked spaghetti stickiness and cooking loss.

Cooking score, which combines instrumental measurements of elasticity and firmness, was obtained as described by Dexter et al (1988). Spaghetti stickiness was obtained as described by Dexter et al (1983). Cooking loss, a measure of the loss of solids to the cooking water, was determined as described by Matsuo et al (1992).

RESULTS

Preliminary Experiments with No. 3 CWAD

The properties of the No. 3 CWAD before and after preprocessing are summarized in Table I. Test weight is increased by preprocessing. Removal of the ash-rich outer layers of the wheat kernel results in a large decrease in wheat ash content. The decrease in wheat kernel weight during preprocessing was consistent with the estimated removal of 8–10% by-products.

The unprocessed wheat had a marginal falling number that improved dramatically after preprocessing. Previously, Liu et al (1986) and Henry et al (1987) showed that wheat falling number is improved after abrasive pearling, and McGee (1992) and Timm (1992) indicated that the Tkac preprocessing system improves the falling number of sprouted wheat. It is well known that α-amylase is concentrated in the embryo and aleurone (Henry et al 1987). Preprocessing removes the bran layer, most of the aleurone layer, and some of the embryo, resulting in reduced α-amylase activity in the preprocessed wheat.

When milled by the routine GRL semolina milling procedure, the preprocessed and processed wheats gave a comparable semolina yield, considered on an unprocessed wheat basis (Table II). However, the preprocessed wheat semolina was more refined,

TABLE I
Properties of Unprocessed (UP) and Preprocessed (PP) No. 3 Canada Western Amber Durum Wheat[a]

Property	UP	PP
Test weight, kg/hl	79.1	82.3
Kernel weight, mg	39.9	35.6
Falling number, sec	120	250
Protein content, %	14.0	14.0
Ash content, %	1.53	1.26

[a] Analytical data are means of duplicate analyses expressed on 14% mb.

TABLE II
Semolina Properties of Unprocessed (UP) and Preprocessed (PP) No. 3 Canada Western Amber Durum Wheat[a]

	UP Temper Time, hr			PP Temper Time, hr		
Property	6	16	16[b]	4	16	16[b]
Semolina yield, %[c]	64.5	63.7	68.5	70.6	71.1	73.9
Unprocessed basis, %[d]	...	...	...	63.5	64.0	66.5
Protein content, %	13.2	13.1	13.5	13.1	13.1	13.1
Wet gluten, %	36.8	35.0	38.1	37.1	37.2	38.1
Ash content, %	0.69	0.71	0.78	0.60	0.63	0.64
Agtron color, %	66	66	59	71	70	66
Specks per 50 cm^2	27	20	46	20	13	30
Falling number, sec	205	185	175	245	245	245

[a] Data are means of duplicate analyses expressed on 14% mb.
[b] Single millings. All other millings duplicated.
[c] Yields expressed as proportion of wheat to first break on a constant moisture basis.
[d] Semolina yields of preprocessed wheat adjusted on basis of 10% loss during preprocessing.

as shown by a lower ash content, a higher Agtron color value, and fewer specks.

In initial experiments, for convenience, the preprocessed and unprocessed wheats were tempered overnight (16 hr). The minimum temper time required for preprocessed wheats is much less than that for unprocessed wheat (McGee 1992, Timm 1992). However, when the wheats were tempered for shorter periods, the improved milling performance of the preprocessed wheat was still apparent (Table II).

When the mill flow was extended to increase semolina yield, the ash content and color of the semolina from the unprocessed wheat deteriorated more than did the preprocessed wheat (Table II). On the basis of ash content and Agtron color, the higher extraction product from the preprocessed wheat was more refined than the lower extraction product from the unprocessed wheat.

The falling number of the semolina from the preprocessed wheat was higher than that for the semolina from the unprocessed wheat (Table II). However, the falling number of the semolina from the preprocessed wheat exhibited no improvement over the preprocessed wheat value. It is well known that during the milling of unprocessed durum wheat, the falling number of semolina increases due to removal of α-amylase-rich tissues (Dexter et al 1990). Results of the current study would indicate that preprocessing removes α-amylase-rich tissue more efficiently than does conventional milling of unprocessed durum wheat.

The color properties of the spaghetti samples processed from the preprocessed wheat were slightly brighter and less brown (shorter dominant wavelength) than those of the unprocessed wheat, particularly when dried at 70°C (Table III). When milled to higher extraction, the brightness and dominant wavelength of the spaghetti from the preprocessed wheat approached that of the spaghetti prepared from lower extraction unprocessed wheat semolina.

Spaghetti purity, an indication of color intensity, was slightly lower for the preprocessed wheat products (Table III). Although readily detectable instrumentally, the drop in color intensity in the preprocessed spaghetti was barely discernable by eye.

Wheat yellow pigment content increases from the inner to the outer portion of the wheat kernel (Matsuo and Dexter 1980). According to McGee (1992), the removal of pigment-rich fractions from the outer regions of the wheat kernel during preprocessing reduces the pigment level of common wheat flour. The removal of pigment in bread flour is desirable in most markets because of consumer preference for a bright white crumb. In contrast, the removal of pigment from durum wheat during preprocessing is not desirable because in many markets consumers prefer bright

TABLE III
Spaghetti Properties of Unprocessed (UP) and Preprocessed (PP) No. 3 Canada Western Amber Durum Wheat[a]

	UP Temper Time, hr			PP Temper Time, hr		
Property	**6[b]**	**16[b]**	**16[c]**	**4[b]**	**16[b]**	**16[c]**
Spaghetti dried at 39°C						
Color						
Brightness, %	48.9	48.9	48.0	49.0	49.2	48.5
Purity, %	39.6	41.6	41.3	40.2	41.0	38.0
Dominant wavelength, nm	576.6	576.7	576.9	576.5	576.6	576.8
Cooking quality						
Cooking score, units	69	70	54	49	55	52
Stickiness, N/m^2	1,210	1,270	1,180	1,200	1,160	1,140
Cooking loss, %	7.5	6.7	6.6	7.0	7.3	6.9
Spaghetti dried at 70°C						
Color						
Brightness, %	49.1	49.0	46.5	49.1	49.4	48.8
Purity, %	42.0	43.3	38.4	41.5	38.5	37.2
Dominant wavelength, nm	577.2	577.2	577.9	576.9	576.9	577.1
Cooking quality						
Cooking score, units	64	68	68	63	71	66
Stickiness, N/m^2	1,160	1,060	1,080	1,160	1,140	1,130
Cooking loss, %	5.4	5.6	5.5	5.5	5.8	5.9

[a] Data are means of duplicate analyses.
[b] Milled by standard milling procedure.
[c] Milled to higher extraction by extending break and sizing system.

TABLE IV
Preprocessing Summary (%) for No. 1 Canada Western Amber Durum and Ontario Durum Wheats[a]

	Wheat			By-Product		
Preprocessing Stage	**Yield**	**Protein Content**	**Ash Content**	**Yield**	**Protein Content**	**Ash Content**
Canada Western Amber Durum[b]						
Friction-1	95.2	12.2	1.53	4.8	10.4	3.99
Friction-2	93.8	11.9	1.56	1.4	13.1	4.83
Abrasion-1	91.5	11.9	1.32	2.3	17.1	6.57
Abrasion-2	89.1	11.8	1.15	2.4	17.0	6.16
Abrasion-3	87.1	11.6	1.02	2.0	16.1	5.48
Ontario durum[c]						
Friction-1	95.1	16.4	2.01	4.9	12.5	4.00
Friction-2	92.4	16.2	1.96	2.8	14.9	5.03
Abrasion-1	88.1	16.1	1.68	4.3	19.6	6.37
Abrasion-2	83.9	15.9	1.44	4.2	20.2	5.82
Abrasion-3	81.0	15.9	1.33	2.8	21.8	4.71

[a] Yields expressed as proportion of unprocessed wheat on constant moisture basis. Protein content (N × 5.7) and ash content are means of duplicate analyses expressed on 14% mb.
[b] Mean values from duplicate preprocessings.
[c] Data from a single preprocessing.

yellow pasta.

Preprocessing had little effect on cooked spaghetti firmness and resilience (cooking score), surface stickiness, or solids lost during cooking (Table III).

Experiments with No. 1 CWAD and Ontario Durum

The preprocessing results for the No. 1 CWAD and Ontario durum wheats are summarized in Table IV. During the trials, preprocessing was not considered complete after two abrasion passages, so an additional abrasion passage was added.

The No. 1 CWAD was preprocessed twice. The results of the two preprocessings were very similar. So, all No. 1 CWAD results are mean values of both preprocessings. Due to limited sample size, the Ontario durum was preprocessed once.

The poorer physical condition of the Ontario durum is reflected by lower kernel weight and lower test weight than that of the No. 1 CWAD (Table V). To fully remove the seed coat of the Ontario durum during preprocessing, the amount of by-product removed was increased deliberately by reducing the feed rate to the polisher at all preprocessing stages. As a result, 19% of the seed coat was removed during preprocessing of the Ontario durum, compared to 12.9% for the No. 1 CWAD.

An economic advantage cited for the preprocessing system is increased by-product revenue due to the distinct properties of the sequentially removed bran layers (Timm 1992). As seen in Table IV, the by-products in the current study exhibited a wide variability in protein content and ash content, verifying that bran layers were removed sequentially. The fiber contents and other constituents of the by-products are described in detail elsewhere (McGee 1992).

The ash content of the wheat decreases progressively during preprocessing due to concentration of ash in the by-products. Wheat protein content increases during the initial friction stage (Tables IV and V) due to the low protein content of the outer bran layer. During the abrasion stage, the by-products are rich in aleurone, as reflected by high protein content. As a result, wheat protein content declines. The protein present in bran and aleurone is predominantly nongluten protein (MacMasters et al 1971), so loss of protein during preprocessing is predominantly nongluten protein.

The protein content of the third abrasion by-product was lower than that of the second abrasion by-product for CWAD (Table IV). If, as this suggests, the endosperm layer was penetrated during the last abrasion step, then the CWAD preprocessing was excessive, and maximum milling potential would not be realized because of loss of endosperm in the by-product. In contrast, the protein content of the abrasion by-products of the Ontario durum wheat increased throughout processing, indicative of proper preprocessing.

Detailed analyses of the unprocessed and preprocessed wheats are summarized in Table V. Both unprocessed wheats had high falling numbers and low α-amylase activity. Nevertheless, after preprocessing, both wheats exhibited higher falling numbers due to reduced α-amylase activity.

Polyphenol oxidase (PPO) has been implicated in pasta browning (Kobrehel et al 1972, 1974), and is concentrated in the branny layers of wheat (Marsh and Galliard 1986, Hatcher and Kruger 1993). Therefore, in view of the brighter, less brown color of the spaghetti from preprocessed durum wheat in preliminary experiments (Table III), PPO activities were performed on the unprocessed and preprocessed wheats. PPO activity declined during preprocessing (Table V). However, the low level of PPO found in both unprocessed wheats makes it unlikely that PPO activity is a major factor determining spaghetti color for these wheats.

It was confirmed that yellow pigment content is decreased by preprocessing (Table V). Gluten protein quality, as measured by the SDS-sedimentation test was not influenced by preprocessing.

The milling results for both wheats showed a clear advantage in milling performance attributable to preprocessing (Table VI). Cumulative ash contents of all milling products, including the combined by-products, were in close agreement to the ash content of the unprocessed wheats, confirming the estimates of by-product yields during preprocessing.

The yields of semolina and granulars (semolina and flour combined) on an unprocessed wheat basis were not affected by pre-

TABLE V
Properties of Unprocessed (UP) and Preprocessed (PP) No. 1 Canada Western Amber Durum (CWAD) and Ontario Durum Wheats[a]

	No. 1 CWAD		Ontario Durum	
Property	UP	PP	UP	PP
Test weight, kg/hl	83.0	84.9	70.9	79.8
Kernel weight, mg	42.5	39.0	34.0	28.1
Falling number, sec	470	545	305	345
α-Amylase, units/g	2.5	1.8	73.5	51.5
Polyphenol oxidase, units/g	218	100	232	102
Protein content, %	12.0	11.6	16.2	15.9
SDS[b] sedimentation, ml	34	30	37	42
Yellow pigment, ppm	7.2	6.7	9.0	8.4
Ash content, %	1.62	1.02	2.04	1.35

[a] Analytical data are means of duplicate analyses expressed on 14% mb. CWAD data are mean values from duplicate preprocessings. Ontario durum data are from a single preprocessing.
[b] Sodium dodecyl sulfate.

TABLE VI
Milling Summary (%) for Unprocessed and Preprocessed No. 1 Canada Western Amber Durum (CWAD) and Ontario Durum Wheats[a]

	Unprocessed				Preprocessed			
			Cumulative				Cumulative	
Milling Product	Yield	Ash Content	Yield	Ash	Yield	Ash Content	Yield	Ash
CWAD[b]								
Semolina	64.2	0.69	64.2	0.69	65.7	0.58	65.7	0.58
Flour	10.4	1.28	74.6	0.77	9.5	1.08	75.2	0.64
Purifier discards	4.9	3.17	79.5	0.92	3.6	2.80	78.8	0.74
Bran	11.7	4.73	91.2	1.41	3.5	4.06	82.3	0.88
Shorts	6.9	4.90	98.1	1.65	3.3	4.28	85.6	1.02
By-products	...	...	...	...	12.9	5.10	98.8	1.55
Ontario Durum[c]								
Semolina	61.6	0.94	61.6	0.94	60.8	0.76	60.8	0.76
Flour	8.1	1.96	69.7	1.05	7.1	1.65	67.9	0.85
Purifier discards	6.5	3.55	76.2	1.26	4.7	3.24	72.6	1.00
Bran	12.4	4.42	88.6	1.71	2.5	4.20	75.1	1.11
Shorts	9.2	5.18	97.8	2.04	4.3	4.60	79.4	1.29
By-products	...	...	...	...	19.0	5.31	98.4	2.07

[a] Yields expressed as proportion of unprocessed wheat on constant moisture basis. Ash contents are means of duplicate analyses expressed on 14% mb. Yields and ash contents of preprocessing by-products are computed from yields and ash contents of individual fractions.
[b] CWAD data are mean values from duplicate preprocessings.
[c] Ontario durum data are from a single preprocessing.

processing for either wheat (Table VI). However, the ash content of semolina from the preprocessed wheats was much lower than that of the corresponding unprocessed wheats. The yield of granulars from the preprocessed wheats was about 10% higher than the yield of semolina from the unprocessed wheats. Nevertheless, the ash content of the preprocessed granulars are lower. Ash content is a well-recognized durum wheat semolina refinement index (Dexter et al 1987). In markets where durum wheat millers must meet a maximum semolina ash content specification, preprocessing appears to offer a very significant yield advantage.

Analytical analysis of the semolina and granulars from the wheats confirmed that the loss of wheat protein during preprocessing was not gluten protein. For both semolina and granulars, neither protein content nor wet gluten content were affected by preprocessing (Table VII). In contrast, the loss of wheat yellow pigment from preprocessing imparted a drop in the yellow pigment content of semolina and granulars for both wheats.

In addition to the lower ash content discussed above, the superior refinement of the semolina and granulars from the preprocessed wheats was reflected by higher Agtron color and reduced speckiness. These trends were most apparent for the Ontario durum wheat. The granulars from the preprocessed Ontario durum wheat equalled the Agtron color and the speck count of the semolina from the unprocessed Ontario durum wheat.

PPO activity was lower in the preprocessed wheat products (Table VII). Preprocessing had little effect on falling number of semolina or granulars, because both unprocessed wheats had relatively high falling numbers.

As seen in Table VIII, preprocessing resulted in a brighter, less brown (shorter dominant wavelength) spaghetti for both wheats and for both drying regimes. When dried by the 70°C drying cycle, which simulates one of the most popular current commercial drying cycles (Baroni 1988), the granulars from the preprocessed wheats equalled the brightness and the dominant wavelength of the corresponding semolina from the unprocessed wheats.

There was clear evidence that spaghetti pigment intensity (purity) of the CWAD was reduced by preprocessing (Table VIII). However, spaghetti purity was not reduced by preprocessing of the Ontario durum wheat, perhaps due to the greater improving effect of preprocessing on semolina and granulars refinement compared that of the CWAD. Pigment loss during spaghetti processing

TABLE VII
Semolina and Granulars Properties of Unprocessed (UP) and Preprocessed (PP) No. 1 Canada Western Amber Durum (CWAD) and Ontario Durum Wheats[a]

	No. 1 CWAD[b]				Ontario Durum[c]			
	Semolina		Granulars		Semolina		Granulars	
Property	UP	PP	UP	PP	UP	PP	UP	PP
Semolina yield, %[d]	64.2	75.4	74.6	86.2	61.6	75.1	69.7	83.8
Unprocessed basis, %[e]	...	65.7	...	75.1	...	60.8	...	67.9
Protein content, %	11.5	11.4	11.4	11.5	15.5	15.7	15.7	15.9
Wet gluten, %	31.7	31.0	31.1	31.3	44.7	44.7	44.7	44.8
Ash content, %	0.69	0.58	0.76	0.63	0.94	0.76	1.06	0.86
Agtron color, %	75	77	67	69	24	38	14	25
Yellow pigment, ppm	6.5	6.2	6.5	6.2	7.8	7.4	8.0	7.3
Polyphenol oxidase, units/g	23	9	25	11	8	6	16	9
Specks per 50 cm^2	39	27	37	33	169	112	170	116
Falling number, sec	645	685	620	640	380	365	355	340

[a] Data are means of duplicate analyses expressed on 14% mb.
[b] Means of duplicate preprocessings.
[c] Data from a single preprocessing.
[d] Yields expressed as proportion of wheat to first break on a constant moisture basis.
[e] Semolina yields of preprocessed wheats adjusted on basis of by-products lost during preprocessing (see Table VI).

TABLE VIII
Properties of Spaghetti Processed from Semolina and Granulars Milled from Unprocessed (UP) and Preprocessed (PP) No. 1 Canada Western Amber Durum (CWAD) and Ontario Durum Wheats[a]

	No. 1 CWAD[b]				Ontario Durum[c]			
	Semolina		Granulars		Semolina		Granulars	
Property	UP	PP	UP	PP	UP	PP	UP	PP
Spaghetti dried at 39°C								
Color								
Brightness, %	51.6	52.0	48.9	49.7	39.4	42.2	36.4	38.7
Purity, %	42.5	39.1	42.9	40.2	37.7	39.2	37.5	39.5
Dominant wavelength, nm	576.6	576.2	576.9	576.6	578.8	578.2	579.6	578.8
Cooking quality								
Cooking score, units	31	27	38	33	64	77	59	71
Stickiness, N/m^2	935	935	805	975	540	615	495	460
Cooking loss, %	5.3	5.9	5.3	5.5	4.7	5.0	4.5	4.7
Spaghetti dried at 39°C								
Color								
Brightness, %	49.7	50.2	48.2	49.8	35.8	39.1	33.6	38.8
Purity, %	46.1	43.3	45.5	41.3	44.7	45.1	40.5	39.5
Dominant wavelength, nm	577.3	576.6	577.4	576.9	581.1	579.6	582.2	580.1
Cooking quality								
Cooking score, units	52	56	53	53	124	120	99	121
Stickiness, N/m^2	550	655	490	595	485	505	470	480
Cooking loss, %	5.2	5.5	5.3	5.4	4.5	4.5	4.5	4.6

[a] Data are means of duplicate analyses expressed on 14% mb.
[b] Means of duplicate preprocessings.
[c] Data from a single preprocessing.

decreases as semolina refinement improves (Matsuo and Dexter 1980, Dexter et al 1985).

Cooked spaghetti texture was not influenced greatly by preprocessing. There was an indication that spaghetti cooking score (firmness and resilience) of the Ontario durum was improved by preprocessing, but this was not apparent for the CWAD (Table VIII). There was some evidence that the preprocessed products may be slightly sticker and exhibit slightly higher cooking loss, but the effects were too slight to be of practical importance.

DISCUSSION

There are a number of important factors associated with commercial preprocessing that could not be evaluated by these small-scale experiments. The robustness of the preprocessing system, both in terms of equipment and consistency of milling performance, still needs commercial verification. Preprocessing allows simplification of the mill flow (Timm 1992), but in these experiments, the preprocessed and unprocessed wheats were milled under identical conditions using a short mill flow (compared to a commercial mill flow) on a small-scale experimental mill. This approach allowed direct comparison of the milling performance of unprocessed and preprocessed wheats under proven precise conditions.

Despite these shortcomings, the results of this study provide strong evidence that preprocessing of durum wheat offers advantages over conventional roller milling of durum wheat. When milled to the same degree of refinement as that of unprocessed wheat, the preprocessed wheat offers a distinct milling yield advantage. Alternatively, when the miller chooses not to increase extraction rate, the better refinement of semolina from preprocessed durum wheat results in brighter, less brown spaghetti. In addition, the enhanced milling performance of preprocessed wheat may allow the miller to compromise on raw material quality, thereby lowering cost without sacrificing semolina quality. Another potential benefit of preprocessing is improved return from by-products (Timm 1992).

The only negative quality effect of preprocessing identified in the current study was a slight decrease in spaghetti color intensity. Preprocessing does not appear to affect cooked spaghetti texture.

A potential disadvantage of preprocessing is that it requires power. However, according to Timm (1992), the increased power consumption may be at least partially compensated for by reduced power consumption during milling due to mill flow simplification.

ACKNOWLEDGMENTS

We are grateful to Refaccionaria de Molinos and Robinson Milling Systems for their cooperation during the pilot-scale preprocessings. J. J. Lachance, G. Holowka, R. W. Daniel, and M. Lymych provided excellent technical assistance. We are grateful to D. W. Hatcher for performing polyphenol oxidase assays.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 08-01, revised October 1981; Method 14-30, revised November 1987; Method 38-11, approved April 1961. The Association: St. Paul, MN.

BARONI, D. 1988. Manufacture of pasta products. Pages 191-216 in: Durum Wheat Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

BLACK, H. C. 1966. Laboratory purifier for durum wheat semolina. Cereal Sci. Today 11:553.

BRADBURY, D., CULL, I. M., and MacMASTERS, M. M. 1956. Structure of the mature wheat kernel. I. Gross anatomy and relationships of parts. Cereal Chem. 33:329.

DAUN, J. K. 1978. Mathematical model for estimating color of spaghetti and mustard flour. Cereal Chem. 55:692.

DEXTER, J. E., and MATSUO, R. R. 1982. Effect of smudge, blackpoint, mildewed kernels, and ergot on durum wheat quality. Cereal Chem. 59:93.

DEXTER, J. E., and TIPPLES, K. H. 1987. Wheat milling at the Grain Research Laboratory. Part 2. Equipment and procedures. Milling 180(7):16.

DEXTER, J. E., MATSUO, R. R., KOSMOLAK, F. G., LEISLE, D., and MARCHYLO, B. A. 1980. The suitability of the SDS-sedimentation test for assessing gluten strength in durum wheat. Can. J. Plant Sci. 60:25.

DEXTER, J. E., MATSUO, R. R., MORGAN, B. C. 1981. High temperature drying: Effect on spaghetti properties. J. Food Sci. 46:1741.

DEXTER, J. E., KILBORN, R. H., MORGAN, B. C., and MATSUO, R. R. 1983. Grain Research Laboratory compression tester: Instrumental measurement of cooked spaghetti stickiness. Cereal Chem. 60:139.

DEXTER, J. E., MATSUO, R. R., LACHANCE, J. J., MORGAN, B. C., and DANIEL, R. W. 1985. Veränderungen am Programm zur Beurteilung der Durum Weizenqualität der kanadischen Getreideforshungsanstalt. Getreide Mehl Brot 39:131.

DEXTER, J. E., MATSUO, R. R., and MARTIN, D. G. 1987. The relationship of durum wheat test weight to milling performance and spaghetti quality. Cereal Foods World 32:772.

DEXTER, J. E., MARTIN, D. G., and MATSUO, R. R. 1988. The effect of roll flute orientation on durum wheat experimental milling performance and semolina quality. Can. Inst. Food Sci. Tech. J. 21:187.

DEXTER, J. E., MATSUO, R. R., and KRUGER, J. E. 1990. The spaghetti-making quality of commercial durum wheat samples with variable alpha-amylase activity. Cereal Chem. 67:405.

GROSH, G. M., SHELLENBERGER, J. A., and FARRELL, E. P. 1960. Milling properties of wheat in relation to pearling, scouring, and impaction. Cereal Chem. 37:593.

HATCHER, D. W. and KRUGER, J. E. 1993. Distribution of polyphenol oxidase in flour millstreams of Canadian common wheat classes milled to three extraction rates. Cereal Chem. 70:51.

HENRY, R. J., MARTIN, D. J., and BLAKENEY, A. B. 1987. Reduction of the α-amylase content of sprouted wheat by pearling and milling. J. Cereal Sci. 5:155.

KOBREHEL, K., LAIGNELET, B., and FEILLET, P. 1972. Relation entre les activités peroxydasiques et polyphenol oxydasiques des blés durs et la brunissement des pâtes alimentaires. C. R. Acad. Agric. 58:1099.

KOBREHEL, K., LAIGNELET, B., and FEILLET, P. 1974. Study of some factors of macaroni brownness. Cereal Chem. 51:675.

KRUGER, J. E., and TIPPLES, K. H. 1979. Relationship between falling number, amylograph viscosity, and α-amylase activity in Canadian wheat. Proc. Int. Sprouting Symp. 2nd. M. D. Gale and V. Stoy, eds. Cereal Res. Commun. 8:97.

LIU, R., LIANG, Z., POSNER, E. S., and PONTE, J. G. 1986. A technique to improve functionality of flour from sprouted wheat. Cereal Foods World 31:471.

MacMASTERS, M. M., HINTON, J. J. C., and BRADBURY, D. 1971. Microscopic structure and composition of the wheat kernel. Pages 51-113 in: Wheat: Chemistry and Technology, 2nd ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St.Paul, MN.

MARSH, D. R., and GALLIARD, T. 1986. Measurement of polyphenol oxidase activity in wheat-milling fractions. J. Cereal Sci. 4:241.

MATSUO, R. R., and DEXTER, J. E. 1980. Comparison of experimentally milled durum wheat semolina to semolina produced by some Canadian commercial mills. Cereal Chem. 57:117.

MATSUO, R. R., BRADLEY, J. W., and IRVINE, G. N. 1972. Effect of protein content on the cooking quality of spaghetti. Cereal Chem. 49:707.

MATSUO, R. R., MALCOLMSON, L. A., EDWARDS, N. M., and DEXTER, J. E. 1992. A colorimetric method for estimating spaghetti cooking losses. Cereal Chem. 69:27.

McGEE, B. 1992. Robinson's Trigotec system. Assoc. Operative Millers Bull. (Feb.): 6001.

POMERANZ, Y. 1961. The problems involved in "peeling" of wheat kernels. Cereal Sci. Today 6:76.

REMO. 1989. Vertijet VJ III. Descascaradora y Pulidora de Granos. Folleto No. 078. Refaccionaria de Molinos, S.A.: México, D.F.

SATAKE, R. S. 1990. Debranning process is new approach to wheat milling. World Grain 8(6):28.

SUGDEN, D. 1991. Tkac and Timm process: A flour miller's point of view. World Grain 9(4):16.

TIMM, J. 1992. Commercial aspects of milling preprocessed wheat. Assoc. Operative Millers Bull. (Feb.): 6095.

TIPPLES, K. H. 1971. A note on sample size error in the falling number test. Cereal Chem. 48:85.

TKAC, J. J. 1992. Process for removing bran layers from wheat kernels. U.S. Patent 5,082,680.

WASSERMAN, T., FERREL, R. E., and PENCE, J. W. 1970. Mechanical debranning of whole-kernel wheat. I. Engelberg and McGill rice mills. Cereal Sci. Today 15:134.

WASSERMAN, T., MOSSMAN, A. P., and FELLERS, D. A. 1972. Mechanical debranning of whole-kernel wheat. II. CeCoCo pearling

mill. Cereal Sci. Today 17:82.
WELLMAN, W. 1992. Wheat milling process. U.S. Patent 5,089,282.
WILLIAMS, P. C. 1973. The use of titanium dioxide as catalyst for large-scale Kjeldahl determination of the total nitrogen contents of cereal grains. J. Sci. Food Agric. 24:343.
WILLM, C. 1992. Milling industries: New processes for new products. Pages 95-110 in: Cereal Chemistry and Technology: A Long Past and a Bright Future. P. Feillet, ed. Institut de Recherches Technologiques Agroalimentaires des Céréales: Montpellier, France.
ZIEGLER, E., and GREER, E. N. 1971. Principles of Milling. Pages 115-199 in: Wheat Chemistry and Technology, 2nd ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

[Received June 1, 1993. Accepted September 9, 1993.]