Effects of Break-Roll Speed Differential on Product Yield and Semolina Granulation in a Durum Pilot Mill System

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ABSTRACT

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Changes in break-roll speed differential in a 25-quintal (55-cwt) durum pilot mill system (136 kg/hr feed rate capacity) affected total yield of semolina, flour, and bran; semolina yield from different purifiers; and semolina granulation (150- to 841-µm particle size range). By adjusting the speed differential of the break and chunk roll pairs from 1.5:1 to 2.5:1 to 3.5:1, semolina yield increased significantly from 55 to 67 to 72%, respectively, and bran yield decreased significantly from 24 to 15 to 11%, respectively. Shorts yield was not affected by speed differential. At 1.5:1, semolina contained 9% flour, compared with 5% flour at 2.5:1 and 3.5:1.

The objective of milling durum wheat is to maximize semolina yield, maintain acceptable semolina color and granulation properties, and minimize flour yield and specks. This can be accomplished by optimizing various mill settings. Typically, durum mills use corrugated break rolls to produce granular semolina, which results from shear or cutting action on particles (Posner and Hibbs 1997). Comparatively, flour mills use a combination of corrugated rolls in break sections and smooth rolls in reduction sections. Smooth rolls maximize compressive forces on particles, resulting in finer granulation. The physical condition and properties of wheat also affect yield, color, and granulation. Dexter and Matsuo (1978) and Matsuo and Dexter (1980) obtained semolina yields of 58–76% by increasing the number of purification stages and widening the roll gaps on break rolls. Higher extractions resulted in higher semolina ash content and a decrease in semolina brightness but had no effect on dough farinograph characteristics.

Scanlon and Dexter (1986) reported that an increase in roll velocity and differential and a decrease in feed rate resulted in an increase in flour yield when grinding farina through a set of smooth rolls. Also, the increase in roll speed differential caused more flour starch damage and water absorption and deterioration in flour quality. Hsieh et al (1980) showed increasing trends in percent weight and ash and protein contents of first break products (except overtails) of Canada Western Red Spring wheat as roll (corrugated) speed differential increased from 1.5:1 to 3:1. Hareland and Shi (1997) reported that interactions of flute angle, corrugation, and speed differential orientations had significant effects on first break release through a 1,295-µm sieve and on first break semolina and flour yields. In contrast, little information is available on the effects of these variables in a complete mill system.

The objective of this study was to determine the effects of break roll speed differential on semolina yield and granulation and on flour, shorts, and bran yields from a 25-quintal (55-cwt) durum pilot mill. Roll flute angle, orientation, corrugation, and feed rate remained constant.

MATERIALS AND METHODS

Durum Wheat

Durum cvs. Renville and Rugby were each obtained from four separate lots and used in pilot milling trials. Cleaned wheat (≈45 kg/batch) was tempered in a stainless steel, rotating drum (Standard Industries, Fargo, ND) powered by a Dayton 0.5-hp motor. The center shaft was fitted with three spray nozzles and connected to a 18.9-L stainless steel container. Water (weight calculated to increase pretempered wheat from 12 to 16.5% wb) was added to the container, which was pressurized to deliver a uniform spray on wheat. Tempered wheat was rotated in the drum for 30 min, transferred to a 114-L sealed plastic container, and stored for 4 hr. Tempered wheat was transferred to a stainless steel bin retrofitted with a screw powered by a Dayton 0.25-hp motor and attached to a speed reducer (D90, Winsmith, Springville, NY), which was adjusted to deliver the wheat to the first break at a flow rate of ≈136 kg/hr (300 lb/hr).

Durum Pilot Mill Flow

The 25-quintal durum pilot mill is located in a four-story complex at North Dakota State University, Fargo: level 1, roll stands; level 2, purifier sections; level 3, sifter sections; and level 4, air locks. Figure 1 is a flow diagram of the mill. The mill consists of 17 pairs of rolls (Creason Corrugating, Wichita, KS), each with 25 × 8 cm (10 × 3 in.) of grinding surface; a sifter (6 × 12 style HS, Great Western, Leavenworth, KS) section operated at 180 rpm, with a 10-cm (4-in.) circle and a total sifter surface capacity of 7.4 m^2 (80 ft^2); two double-stacked purifier (Witt, Witchita, KS) sections, with a total sieve surface capacity of 0.7 m^2 (7.1 ft^2); and three dual purifier (Ocrim America, Minneapolis, MN) sections, with a total sieve surface capacity of 0.4 m^2 (4.5 ft^2). Air locks were purchased from Kice (Wichita, KS).

Roll specifications are shown in Table I. Speed differentials of 1.5:1, 2.5:1, and 3.5:1 were adjusted on first break (1Bk), second break coarse and fine (2BkC and 2BkF, respectively), third break coarse and fine (3BkC and 3BkF, respectively), fourth break (4Bk), fifth break (5Bk), and chunk roll pairs. Fast rolls were set at a velocity of 350 rpm, and slow roll velocities were changed to obtain the indicated differentials. The speed differential of the other roll pairs and other mill variables remained constant during mill runs, as indicated in Table I.

Purifiers were adjusted to isolate semolina fractions from six of eight purifier sections and transfer coarse middling stock to other mill sections. Semolina was isolated from purifiers P1 and P2 at 14 of 18 diverter valves located at the base of the purifiers, from purifier P3A at three of four valves, and from purifiers P4A, P5A, and P5B at two of four valves. Semolina was not recovered from purifiers P3B and P4B, but the coarse middlings produced were transferred to break and sizing rolls for additional grinding. The purifier settings, as described, were used throughout all mill runs.

Durum Milling

A typical mill run began at the time tempered wheat was discharged to the first break and ended when discharge to the first break was completed. Purified semolina stock was collected 5 min after the beginning of the mill run and for 8 min after the end of the mill run. Semolina produced before and after this time interval

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was included in the total semolina yield but not blended with purified semolina because of higher bran contamination. Semolina was collected from individual purifiers (P1, P2, P3A, P4A, P5A, and P5B) during a 10-min interval 5 min into the mill run. Subsequently, the percent semolina yield from each purifier was calculated on the basis of tempered wheat weight (adjusted to 14% wb) to the first break during the 10-min interval. Flour, shorts, and bran yields were calculated from the weight of tempered wheat delivered to the first break during the total mill run time. All weights were adjusted to 14% wb.

Mill Product Analysis

Kernel test weight, moisture, ash, protein, and hardness were determined by Approved Methods (AACC 1995). Kernel weight was determined from 10 g of cleaned, hand-picked seed with a seed counter (Seedburo, Chicago, IL). Kernel size was determined using the method described by Shuey (1960). Semolina granulation was measured from the percent overs and throughs of a Ro-Tap mechanical shaker (100 g of semolina at 5 min) with U.S. Standard sieves: 420, 250, 178, and 150 µm (nos. 40, 60, 80, and 100, respectively).

Statistics

The effects of roll speed differential were determined at three levels on two cultivars (four replicates per cultivar) of durum wheat using a nonrandomized factorial arrangement. Analysis of variance and correlation statistics were applied to product yield and semolina granulation data using statistical software (Statistica Version 5.1, StatSoft, Tulsa, OK).

RESULTS AND DISCUSSION

Durum Wheat Characteristics

Renville and Rugby were selected for this study because together they represent more than 40% of the durum acres planted in North Dakota between 1994 and 1997. Also, Rugby and Renville typically exhibit different dough rheological properties but not necessarily different milling properties. The kernel characteristics of the cultivars are shown in Table II. Rugby had significantly higher test weight and percentage of large kernels and lower kernel hardness than Renville. Kernel weight, protein, and ash did not differ between the two cultivars.

Roll Speed Differential and Product Yield

Roll speed differential had a significant effect on semolina, flour, and bran yields but not on shorts yield, based on means of two durum cultivars and four replicates (Fig. 2). Product yields did not differ significantly between the two cultivars when milled at each of the differential settings. As roll speed differential increased from 1.5:1 to 2.5:1 to 3.5:1, semolina yield increased from 55 (±1.9) to 67 (±3.3) to 72% (±0.5), respectively. Similarly, bran yield decreased from 24 (±2.7) to 15 (±0.9) to 11% (±0.6), respectively. Flour yield decreased from 8 (±0.8) to 5% (±0.6) when the speed differential was increased from 1.5:1 to 2.5:1 and remained at 5% when the differential was increased from 2.5:1 to 3.5:1. In studies on smooth rolls, Scanlon and Dexter (1986) obtained higher flour yields when the velocity of the fast roll was increased to achieve a higher roll speed differential. When using corrugated rolls, Hareland and Shi

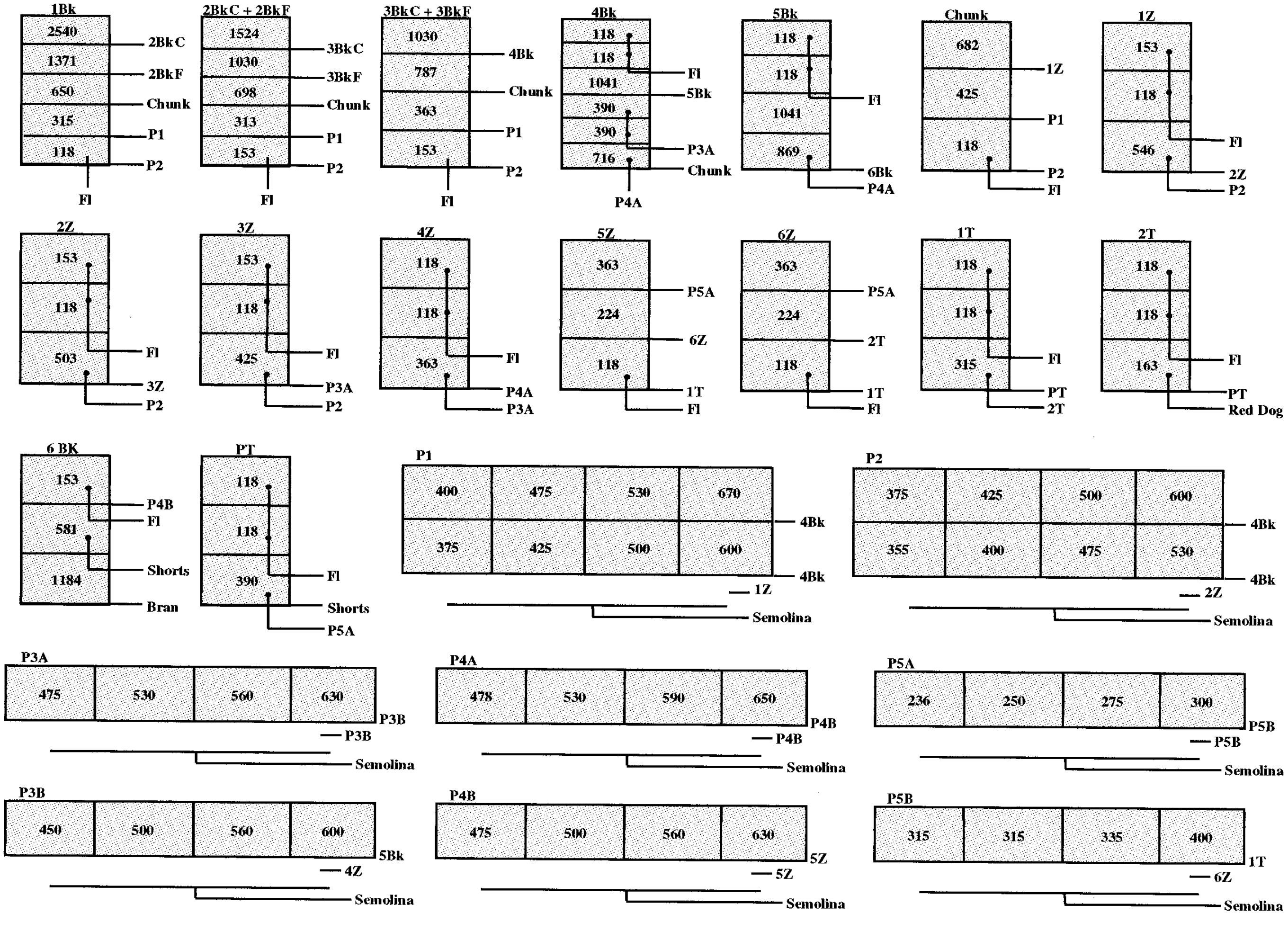

Fig. 1. Flow diagram of the 25-quintal durum pilot mill. Bk = break roll, F = fine, C = coarse, Z = sizing roll, PT = purifier tailing, T = tailing, P = purifier, Fl = flour. Sieve openings are shown in micrometers.

(1997) obtained higher flour yields when the velocity of the slow roll was decreased to achieve a higher speed differential. In these studies, material was ground through one pair of rolls adjusted to different speed differentials, and flour was evaluated after sieving. In contrast, the current study shows the effects on product yield by changing the speed differential in multiple pairs of corrugated rolls in a complete pilot mill system.

The shear and compressive stress forces that act on particles during grinding can cause differences in product yield. Stress forces are caused by roll corrugations and pressure exerted by the rolls (Posner and Hibbs 1997). The magnitude of the stresses vary according to grinding conditions, such as feed rate, roll speed differential, roll gap, and type and condition of roll surface. In terms of maximizing semolina and minimizing flour and bran yields, the 1.5:1 speed differential exerted less shear stress and greater compression on particles, whereas the 3.5:1 differential exerted greater shear and less compression. Therefore, the flour:semolina and bran:semolina ratios were highest at the 1.5:1 differential and lowest at the 3.5:1 differential.

In addition to the shear and compressive forces that affected semolina, flour, and bran yields, the flow of coarse and fine particles through the complete mill system should be considered. The magnitude of stress caused by roll speed differential affected particle size, which subsequently influenced the direction of particle flow in the mill and product yield. Bran and flour (particle size <153 μm) yields were higher at the 1.5:1 differential, and semolina yield was higher at the 3.5:1 differential. Semolina yields from various purifier steams also were different with respect to speed differential (Fig. 3).

The combined purifier semolina yields/10-min mill run/weight of tempered wheat to 1Bk were 25, 28, and 30% at differentials of 1.5:1, 2.5:1, and 3.5:1, respectively. Semolina yields from P1 and P3A increased significantly, whereas semolina from P5A and P5B decreased significantly when speed differential increased from 1.5:1 to 2.5:1 to 3.5:1. Semolina yields from P2 and P4A increased slightly with an increase in speed differential. With the rolls set at a differential of 1.5:1, higher amounts of coarse particles were produced from 1Bk, 2Bk, and 3Bk releases. Subsequently, coarse particles tended to flow to 4Bk, 5Bk, and chunk rolls, because the sieve openings after 1Bk, 2Bk, and 3Bk restricted particle flow to P1. When coarse particles were subjected to successive grinding at 4Bk, 5Bk, and chunk rolls, flour and bran yields were highest. Similarly, P3A semolina yield was lower at the 1.5:1 differential because the coarse particles sized from 1Bk, 2Bk, and 3Bk releases tended to flow more to 4Bk and 5Bk than to the chunk roll. However, at the higher differentials, finer particles were produced from 1Bk, 2Bk, and 3Bk, which caused an increase in flow to the chunk roll. From the chunk roll, the overs of the 682-μm sieve eventually flowed to sizing rolls 3Z and 4Z, which fed P3A from the 425-μm sieve overs and the 363-μm sieve throughs, respectively. P5A and P5B semolina yields were highest at the 1.5:1 differential because large quantities of coarse particles that flowed to the

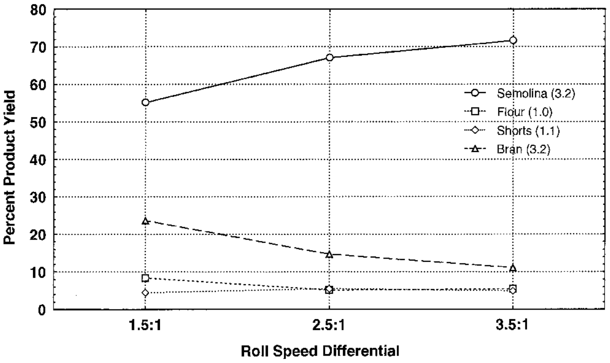

Fig. 2. Effects of roll speed differential on semolina, flour, shorts, and bran yields (n = mean of eight mill runs per differential, least significant difference at α=0.05 indicated in parentheses).

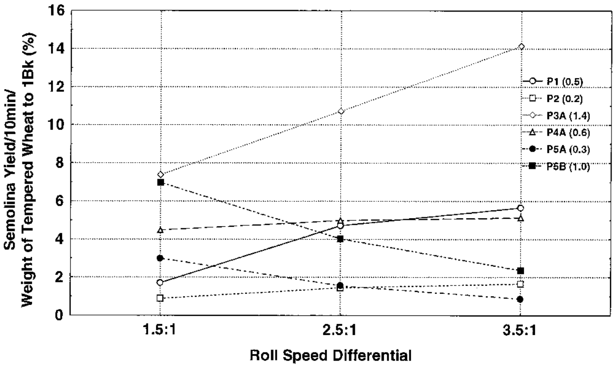

Fig. 3. Effects of roll speed differential on semolina yield from different purifier (P) streams (n = mean of eight mill runs per differential, least significant difference at α=0.05 indicated in parentheses).

TABLE I
Roll Specifications for the Durum Pilot Mill[a]

Roll	Speed Differential[b]	Roll Orientation	Spiral (%)[c]	Corrugation (no./cm)	Flute Angle (degrees)	Roll Speed (rpm) Fast	Roll Speed (rpm) Slow[b]	Roll Gap (mm)
1Bk	Varied	S:S	8.33	3.1	45/60	350	Varied	0.33
2BkC	Varied	S:S	8.33	3.9	40/70	350	Varied	0.31
2BkF	Varied	S:S	8.33	4.7	40/60	350	Varied	0.13
3BkC	Varied	S:S	8.33	5.5	40/60	350	Varied	0.23
3BkF	Varied	S:S	8.33	6.3	40/65	350	Varied	0.13
4Bk	Varied	D:D	8.33	7.8	30/60	350	Varied	0.31
5Bk	Varied	D:D	8.33	9.4	AS	350	Varied	0.18
Chunk	Varied	S:S	8.33	7.9	30/60	350	Varied	0.45
6Bk	2.0:1	D:D	6.25	11.8	AS	350	175	0.26
1Z	2.5:1	S:S	8.33	8.7	30/60	350	140	0.44
2Z	2.5:1	S:S	8.33	9.4	AS	350	140	0.41
3Z	2.5:1	S:S	8.33	10.2	AS	350	140	0.36
4Z	2.5:1	D:D	8.33	11.0	AS	350	140	0.33
5Z	2.5:1	D:D	8.33	11.8	AS	350	140	0.26
6Z	2.5:1	D:D	8.33	13.4	AS	350	140	0.26
1T	1.5:1	…	…	F	F	350	233	Touch
2T	1.5:1	…	…	F	F	350	233	Touch

[a] Bk = break, BkC = break coarse, BkF = break fine, Z = sizing, T = tailing, S = sharp, D = dull, AS = Allis Sharp, F = frosted.
[b] Speed differential of break and chunk rolls varied from 1.5:1 to 2.5:1 to 3.5:1 as the velocity of the slow roll was adjusted to 233, 140, and 100 rpm, respectively.
[c] Spiral inclination.

chunk rolls subsequently flowed to 5Z and 6Z, which fed P5A and P5B. Similarly, as more particles flowed to the sizing and tailing rolls, higher flour yield occurred because of successive grinding. P1 semolina yield was higher at the 2.5:1 and 3.5:1 differentials because a higher portion of particles from 1Bk, 2Bk, and 3Bk releases were reduced in size to cause an increase in particle flow to P1. Similarly, flour and bran yields were lower at the higher differentials because smaller quantities of coarse particles flowed to the successive grinding passages after the 3Bk sections.

Roll Speed Differential and Semolina Granulation

Granulation properties of semolina are important for pasta manufacturers because of the effects on processing, especially hydration rates (Posner and Hibbs 1997). Because of modern continuous pasta processing, finer semolina is in higher demand than coarser semolina used in batch processing (Cubadda 1988, Matsuo 1988). Semolina granulation specifications can be met by adjusting various mill settings, which include purifier settings and sieve sizes.

Semolina granulation was significantly affected by roll speed differential (Fig. 4). Based on the Ro-tap sieve analysis of semolina, a significantly lower percentage of particles remained over the 250-µm sieve at the 1.5:1 differential than at the 3.5:1 differential, and a higher percentage of particles remained over and through the 178- and 150-µm sieves at the 1.5:1 differential than at the 2.5:1 and 3.5:1 differentials. The throughs of the 150-µm sieve yielded 9% flour in semolina at the 1.5:1 differential, compared with 5% flour at the higher differentials. In U.S. commercial durum mills, semolina must not contain more than 3% flour, as determined by sieving through a 150-µm sieve, and all semolina must pass through an 841-µm sieve (Banasik 1981). Other countries, such as Italy (Cubadda 1988) and Canada (Matsuo 1988), have slightly different specifications for semolina particle size. The granulation properties of semolina from individual purifiers are shown in Fig. 5. The particles remaining over the 250-µm sieve predominated in all purifier streams, except P2. A higher portion of finer particles and throughs of the 150-µm sieve were associated with P2. However, P2 also represented <2% of the semolina collected per 10-min run (Fig. 3), which corresponded to <5% of the total semolina collected during an entire mill run. With all purifier streams, the percent throughs of the 150-µm sieve were highest at the 1.5:1 differential, which reflected greater compressive grinding forces on particles. Based on the profiles shown in Fig. 5, semolina with specific granulation properties could be achieved by blending yields from selected purifier streams.

Relationships among Milling Yield, Purifier Yield, and Semolina Granulation

Table III shows the significant ($P < 0.01$) correlation coefficients among milling yields of semolina, flour, shorts, and bran; semolina yield from six purifiers; and semolina granulation from sieve-size distributions. Flour and bran yields were negatively correlated ($r = –0.88$ and –0.93, respectively) with semolina yield, and flour yield was positively correlated ($r = 0.78$) with bran yield. Total semolina yield was positively correlated with purifier yield at P1, P2, P3A, and P4A and negatively correlated with purifier yield at P5A and P5B. The opposite relationship occurred between flour and bran yields and P5A and P5B semolina yields.

CONCLUSIONS

Break-roll speed differential had a significant effect on durum semolina, flour, and bran yields and semolina granulation properties. A low-speed differential resulted in lower semolina yield and higher bran and flour yields, whereas a high-speed differential had the opposite effect. This was attributed to differences in the shear and compressive grinding forces on particles. However, the flow direction of particles in the mill system, middling loads on the sieves and purifiers, and effects of successive grinding passages affected product yields and semolina granulation as well. The durum cultivars used in this study were not significantly different in terms of product yield and semolina granulation; however, the kernel properties of the cultivars exhibited different test weight, size, and hardness. In commercial durum mills, milling variables need to be configured precisely to meet certain objectives related to semolina specifications. Although commercial mills are not con-

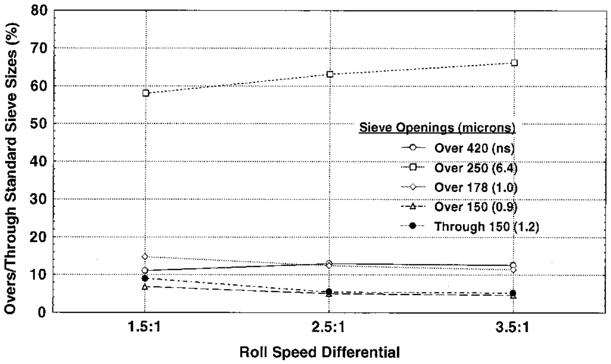

Fig. 4. Effects of roll speed differential on granulation properties of semolina (n = mean of eight mill runs per differential, least significant difference at $\alpha = 0.05$ indicated in parentheses, ns = not significant).

TABLE III
Correlation Coefficient (r) Values of Milling Yield, Purifier Semolina Yield, and Semolina Granulation Variables[a]

Variable[b]	Semolina	Flour	Shorts	Bran
Flour	–0.88			
Shorts	ns	ns		
Bran	–0.93	0.78	ns	
P1	0.98	–0.89	ns	–0.95
P2	0.98	–0.85	ns	–0.95
P3A	0.92	–0.71	ns	–0.85
P4A	0.72	–0.63	ns	–0.64
P5A	–0.95	0.82	ns	0.94
P5B	–0.94	0.81	ns	0.91
No. 40	ns	ns	ns	ns
No. 60	0.62	ns	ns	–0.73
No. 80	–0.90	0.78	ns	0.89
No. 100	–0.93	0.84	ns	0.92
Pan	–0.88	0.81	ns	0.93

[a] Pearson correlation coefficients significant at $P < 0.01$, ns = not significant, $n = 24$

[b] P indicates purifier; no. indicates U.S. Standard sieve.

TABLE II
Characteristics of Durum Wheat Cultivars[a]

Cultivar	Test Weight (kg/hL)	Kernel Weight (mg)	Kernel Size (% large)	Kernel Hardness (NIR)[b]	% Protein (14% wb)	% Ash (14% wb)
Rugby	80.6 (0.7) a	39.5 (3.9) a	72.1 (9) a	128 (6) a	12.5 (0.32) a	1.72 (0.02) a
Renville	78.8 (0.5) b	36.1 (0.8) a	57.2 (3) b	140 (4) b	12.9 (0.38) a	1.78 (0.11) a

[a] Means of four replications (± standard deviation). Means within each column followed by different letters are significantly different at $P < 0.05$.

[b] Near infrared reflectance.

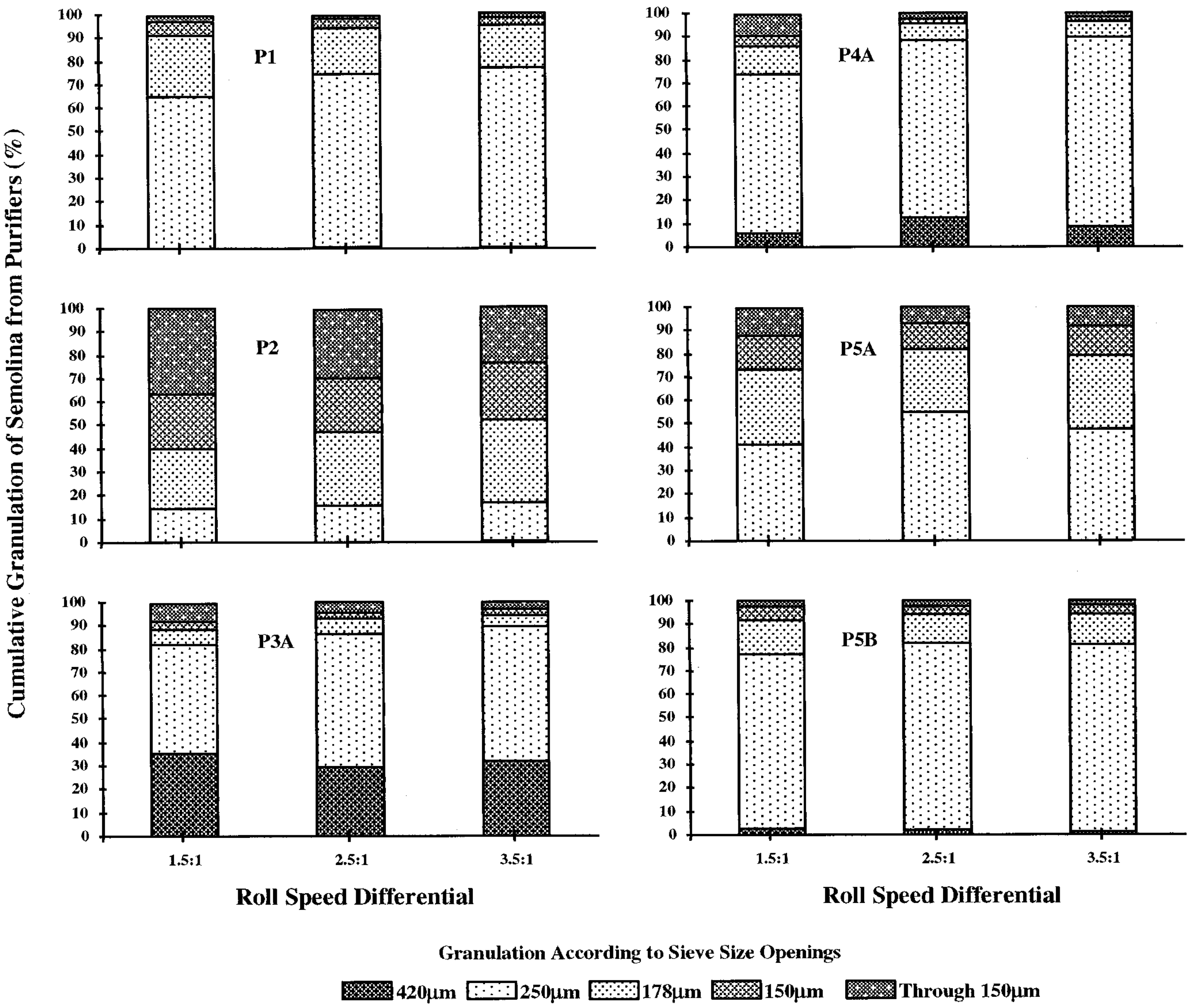

Fig. 5. Granulation properties of semolina from different purifier (P) streams (*n* = mean of eight mill runs per differential).

figured exactly the same, the results obtained from the 25-quintal durum pilot mill system should compare closely with most commercial durum mills.

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