Effects of Break-Roll Differential on Semolina and Spaghetti Quality

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ABSTRACT

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Break-roll differential provides the shearing action needed to remove bran from the endosperm. The effects of break-roll differential on semolina and spaghetti quality were investigated using a 25-quintal (55-cwt/day) durum pilot-mill system. Differentials of each break-roll pair were adjusted to target differentials of 1.5:1, 2.5:1, and 3.5:1 by changing the velocity of the slow roll. Fast rolls were set at a velocity of 350 rpm. Bran specks, ash, and protein increased and semolina brightness (*L* value) and starch damage decreased with increased break-roll differential. Semolina yellowness (*b* value) was greatest with 2.5:1 and least with 1.5:1 differential. Spaghetti brightness (*L* value) and yellowness (*b* value) were lower when spaghetti was made from semolina milled at 3.5:1 than from either 2.5:1 or 1.5:1 differential. Strength of dry spaghetti and spaghetti cooking loss and cooked firmness were not affected by break-roll differential.

Milling performance of durum wheat is evaluated by semolina yield, appearance, and granulation (Dick and Youngs 1988). Milling performance can be optimized for a wheat mix by making certain adjustments to roll speed, gap, and differential while the mill is in operation. The first break-roll pair cracks open the wheat kernel, which allows for efficient separation of bran and endosperm in subsequent break sections. The use of corrugated break-rolls enhances the shearing or cutting action that is required to separate the bran from the endosperm to produce the granular semolina (Posner and Hibbs 1997). The shearing or cutting action of corrugated rolls is a function of the number of corrugations, profile configuration, orientation, spiral, speed, and differential. Break-roll differential typically varies from ≈2.0:1 to 2.5:1 in commercial mills, and the speed of the fast rolls varies from ≈250 to 600 rpm.

Changes in break-roll differential can affect total yield of semolina, flour, and bran; semolina yield from different purifiers; and semolina granulation (Hareland 1998). The long break system, associated with milling durum, allows the release of coarse endosperm particles with a minimum amount of flour being produced. Flour production is minimized by using flutes with sharp profiles on all corrugated rolls in the break and sizing systems and by setting roll pairs at a sharp-to-sharp configuration. Cutting action of the rolls is by the short cutting edge of the flute, which maximizes shearing and reduces the proportion of fines caused by compressive forces produced during grinding. The shearing action of the rolls results in semolina with sharper edges, which intensifies the yellow color (Bizzarri and Morelli 1988).

Break-roll differential can have a significant effect on durum semolina, flour, and bran yields and semolina granulation properties. Hareland (1998) reported that increased break-roll differential resulted in increased semolina yield and decreased bran yield. Differential of 1.5:1 resulted in greater flour and bran yields and lower semolina yield than differentials of 2.5:1 and 3.5:1. This was attributed to differences in the shear and compressive grinding forces on the particles. Break-rolls, which are configured according to flute angle, spiral, orientation, number of corrugations, and roll speed, generally differ from mill to mill.

Hareland and Shi (1997) reported that interactions of flute angle, corrugation, and speed differential had significant effects on first break release through a 1,295-µm sieve and on first break semolina and flour yields. With a sharp-to-sharp orientation, first break semolina yield obtained from two purifier sections ranged from ≈0.65 to 0.90% of the total product yield when the first break-roll differential was set at 1.5:1 and 2.5:1, respectively. By comparison, flour yield ranged from ≈0.16% to 0.26% of the total product yield when the first break-roll differential was set at 1.5:1 and 2.5:1, respectively. The study by Hareland and Shi (1997) was used as a basis for evaluating product yield and semolina granulation in a complete pilot-mill system (Hareland 1998). This study is a continuation of that research. The objective of this study was to determine the effects of break-roll differential on semolina and spaghetti quality.

MATERIALS AND METHODS

Durum Milling

Semolina was obtained from four separate lots of the durum cultivars Renville and Rugby. Wheat was cleaned, tempered, and milled in a 25-quintal (55-cwt/day) durum pilot mill (Fig. 1) according to procedures described by Hareland (1998). 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, second break coarse and fine, third break coarse and fine, fourth break, fifth break, and chunk roll pairs. Fast rolls were set at a velocity of 350 rpm, and slow roll velocities were changed to obtain the desired differentials. The speed differential of the other roll pairs and other mill variables remained constant during mill runs (Table I).

Purifiers were adjusted to isolate semolina fractions from six of eight purifier sections. In Fig. 1, purified semolina was obtained from purifiers P1, P2, P3A, P4A, P5A, and P5B. Semolina from purifiers P3B and P4B was transferred to break and sizing rolls for additional grinding. The same purifier settings were used for all mill runs.

Semolina Analysis

AACC Approved Methods (2000) were used to determine ash (Method 08-01), protein (Method 46-30), and starch damage (Method 76-31) on semolina and reported on a 14% mb. Dough strength was measured using the mixograph (National Manufacturing, Lincoln, NE) according to Approved Method 54-40A, with some modifications. Semolina (10 g, 14% mb) was brought to constant water absorption of 58% and mixed for 8 min in the mixograph bowl (spring setting of 8). Brown (bran) specks in the semolina were counted using a Maztech SPX Speck Expert (Maztech MicroVision Ltd., Ottawa, ON, Canada) (Harrigan and Bussmann 1998). The average of three readings was converted to the number of specks/10 cm^2. Semolina color was measured with a colorimeter (model CR310, Minolta Corp., Ramsey, NJ) using the CIE color scale for L^* and b^* values. *L* values measure black to white (0–100) and *b* values measure yellowness when positive.

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Extrusion

Semolina (800 g) was hydrated to 32% moisture and extruded as spaghetti using a DeMaco semi-commercial laboratory extruder. Extrusion occurred at 45°C, with a mixing chamber vacuum of 46 cm of Hg, and 25 rpm auger extrusion speed. Spaghetti was dried in a laboratory dryer using low temperature (40°C) and high temperature (70°C) drying cycles (Yue et al 1999).

Spaghetti Quality

Color of dry spaghetti was measured with a colorimeter (model CR310, Minolta Corp., Ramsey, NJ). Color readings were expressed by Hunter values for *L* and *b* as for semolina. Spaghetti (10 g) was cooked in 300 mL of boiling water for 12 min. Cooked weight was the weight of 10 g of dry spaghetti after cooking. Cooking loss (weight of total solids [%]) was measured by evaporating the cooking water to dryness in a forced-air oven at 110°C.

Dry spaghetti strength and cooked firmness were measured using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY). Spaghetti strength was measured by the force (g) required to break one strand of dried spaghetti, while the cooked firmness was measured by the energy (g • cm) required to shear five cooked spaghetti strands.

Statistical Analysis

The experiment was conducted using a completely random design with factorial arrangements of three roll differentials and two durum cultivars. Each treatment had four replicates. Data were subjected to analysis of variance. Means were separated by Fishers protected least significant difference (LSD $P < 0.05$).

RESULTS AND DISCUSSION

Semolina Quality

The interaction between cultivar and break-roll differential was not significant for ash content, CIE L^*, or b^* values, protein content, starch damage, and mixogram parameters such as dough development time, peak height, and peak width. For these variables, the effect of break-roll differential was not dependent on cultivar.

Cultivar by break-roll differential interaction was significant for speck count. The speck count was lower with 2.5:1 than 1.5:1 for Rugby but speck counts from both roll differentials were similar for Renville (Table II). Speck count was greatest for both Renville and Rugby when milled with a roll differential of 3.5:1. Ash content was greatest with 3.5:1 and least with 1.5:1 differential (Table III). Ash content can be used as an indicator of bran contamination in semolina or flour because bran contains relatively high levels of ash. This research supports the results of Hsieh et al (1980), who reported an increase in ash content with increased roll differential. Ash content and bran specks generally increase with increased milling extraction rate. Semolina yield increased from 55 to 67 to 72% as break-roll differential was increased from 1.5:1 to 2.5:1 to 3.5:1, respectively (Hareland 1998), which would account for high ash content and speck count with the 3.5:1 differential. Additionally, ro-tap studies reported by Hareland (1998) revealed that semolina of coarser granulation was produced from the 3.5:1 differential as evidenced by a significant increase in weight of particles remaining on a 250-µm sieve. The 1.5:1 differential causes greater compression and less shear stress on particles passing through the break-roll pairs, whereas, the 3.5:1 differential causes less compression and greater shear stress. Greater compression of the 1.5:1 differential is the result of more cutting points between the fast and slow roll as the particles pass through. Subsequently, more flour is being produced in the break sections of the mill with the 1.5:1 differential, which explains the lower ash content, lower yield, and smaller particle size profile of semolina. Break-roll compression also pulverizes the bran to a finer granulation leaving less bran contamination in the semolina.

Break-roll differential affected semolina color. Semolina brightness (*L* value) decreased with increased ash content, hence, semolina brightness was greatest with 1.5:1, intermediate with 2.5:1, and least

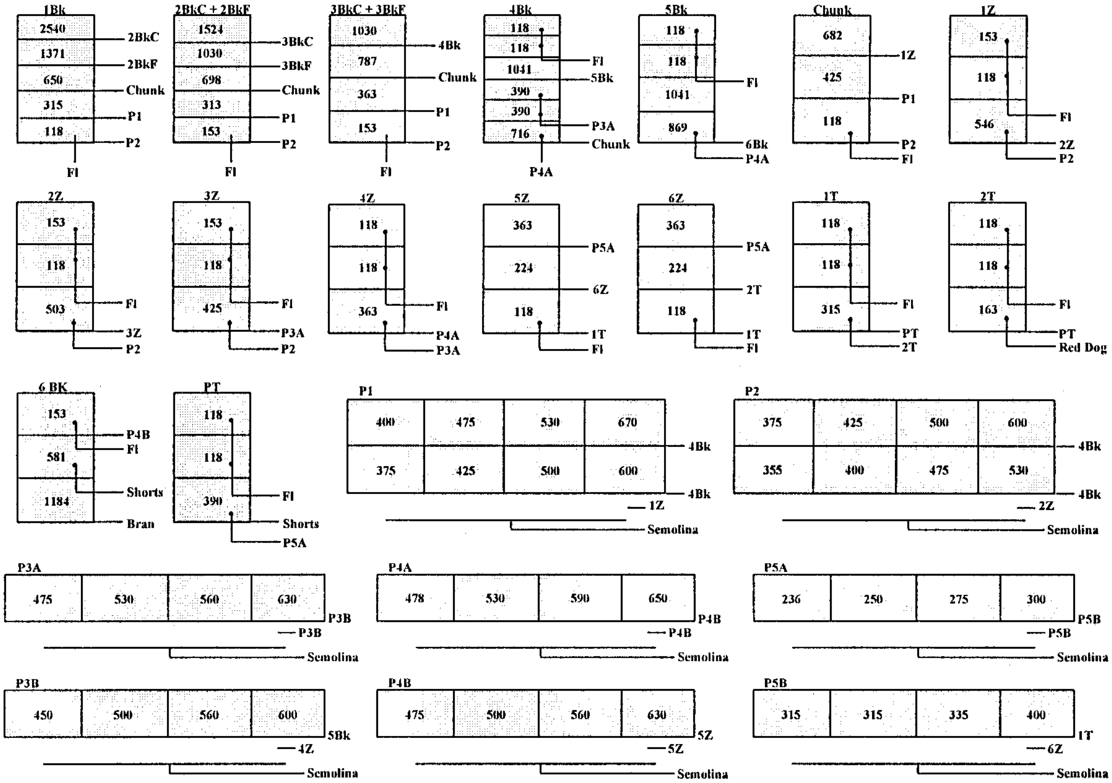

Fig. 1. Flow diagram of the 25-quintal durum pilot mill. Bk = break-roll, F = fine, C = coarse, Z = sizing roll, PT = purifier tailing, T = tailing, P = purifier, Fl = flour. Sieve openings in µm.

TABLE I
Roll Specifications for Durum Pilot Mill[a]

Roll	Speed Differential[b]	Roll Orientation	Spiral (%)[c]	Corrugation (no./cm)	Flute Angle (degrees)	Fast Roll Speed (rpm)	Slow Roll Speed (rpm)[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.

with 3.5:1 differential (Table III). This data supports previous research by Feillet and Dexter (1996). Semolina yellowness (*b* value) was slightly lower with the 1.5:1 differential than with the 2.5:1 and 3.5:1 differentials (Table III), which is attributed to finer granulation. Semolina produced with a 1.5:1 differential had finer granulation than semolina produced with a 2.5:1 or 3.5:1 roll differential (Hareland 1998). This supports previous research of D'Egidio and Pagani (1997). Dexter and Matsuo (1978) indicated that yellow pigment content is not reduced but light reflectance is changed due to particle size. Another likely cause for differences in expression of yellow color is the angle or sharpness of cut on the semolina particles that results from the shearing action of the rolls.

The effect of break-roll differential on protein content was similar for Rugby and Renville, where semolina protein was lowest with 1.5:1 differential, and protein content for 2.5:1 and 3.5:1 was similar (Table III). Semolina protein content corresponds with the level of semolina extraction (Hareland 1998). Protein content increases from the center of the endosperm outward toward the aleurone and bran layer. As milling extraction increases, more endosperm near the bran and aleurone layers is removed, resulting in increased semolina protein content.

Dough development time was affected by break-roll differential. Dough development time was least with 1:5:1 differential and appears to be related to protein content (Table III). The 2.5:1 and 3.5:1 differentials resulted in greater protein content, which was likely the result of increased aleurone and bran in the semolina. With the 3.5:1 differential, dough development time of the semolina was longer than development time of semolina obtained from the 1.5:1 differential. Break-roll differential did not affect peak height or peak width (data not presented).

Starch damage is important in pasta processing as it can affect the hydration rate of semolina during the mixing stage. Uneven hydration of semolina during mixing can result in white specks in the dried pasta. Starch granules that are physically entrapped by the protein matrix in endosperm cells are subject to fracture or damage during milling (Stenvert and Kingswood 1977). The degree of starch damage in various mill fractions depends upon roll variables and efficiency of the purifiers. Hsieh et al (1980) and Scanlon and Dexter (1986) reported that starch damage in flour increases with increased roll differential. Under constant milling conditions, Dexter and Matsuo (1978) had shown that starch damage in semolina increased as semolina extraction increased. In this study however, starch damage in the semolina fraction was greater with the 1.5:1 differential than with either the 2.5:1 and 3.5:1 differentials (Table III). The 1.5:1 differential results in harsher grinding and finer material than the 2.5:1 and 3.5:1 differentials, which can affect the separation of semolina from flour and bran in the purifier system. A decrease in the efficiency of the purifiers in separating flour from semolina when using the 1.5:1 differential would result in the semolina fraction containing more flour with damaged starch. Starch damage was not measured in the flour fractions in this study and is subject to further investigation.

Spaghetti Quality

Cultivar by break-roll differential, drying temperature by break-roll differential, and cultivar by drying temperature by break-roll differential interactions were not significant for dry spaghetti strength, spaghetti color, or cooking quality. Break-roll differential did not affect the strength of dried spaghetti nor the cooked weight, cooked firmness, or cooking loss of spaghetti (Table IV).

Break-roll differential did affect spaghetti color. Spaghetti brightness (*L* value) and yellowness (*b* value) were lower with semolina produced with 3.5:1 than with either 2.5:1 or 1.5:1 differential (Table IV). Dexter and Matsuo (1978) reported greater pigment loss during pasta processing and reduced spaghetti brightness with high compared with low semolina extraction rates. Yellowness of spaghetti was similar when made from semolina produced by 1.5:1 and 2.5:1 differential. This indicates that the relatively low yellow color of semolina from the 1.5:1 differential (Table III) was due to differences in light reflectance from fine and coarse semolina particles and not from pigment loss during milling. Seyam et al (1974) also found that semolina color decreased with increase in fine particles, but when processed there was no affect on spaghetti color.

CONCLUSIONS

The data indicate that the 2.5:1 differential resulted in near optimum semolina and spaghetti quality. Bran specks, ash content and protein content in semolina increased and starch damage decreased with increased roll differential. The higher number of bran specks and ash content with 3.5:1 compared with 1.5:1 differential resulted in reduced semolina brightness. Break-roll differential affected the appearance but not the strength or cooking quality of spaghetti. Spaghetti brightness (*L* value) and yellowness (*b* value) were lower when spaghetti was made from semolina milled at 3.5:1 than from either 2.5:1 or 1.5:1 break-roll differential.

TABLE II
Cultivar by Break-Roll Differential Interaction for Semolina Speck Count (specks/10 cm^2)

Cultivar	Break-Roll Differential 1.5:1	 2.5:1	 3.5:1
Renville	6.7	8.3	12.6
Rugby	9.4	6.7	14.9
LSD[a]		2.4	

[a] Least significant difference ($P < 0.05$) for interaction between break-roll differential and cultivar.

TABLE III
Effect of Break-Roll Differential (BRD)[a] on Semolina Quality

BRD	Ash (%)[b]	CIE *L**	CIE *b**	Protein (%)[b]	DDT (min)[c]	Starch Damage (%)
1.5:1	0.64	83.88	28.39	11.6	3.0	2.25
2.5:1	0.68	82.47	30.86	12.0	3.4	2.07
3.5:1	0.77	81.04	30.41	12.1	3.5	2.04
LSD[d]	0.03	0.34	0.42	0.2	0.3	0.08

[a] BRD averaged across cultivars.

[b] 14% mb.

[c] Dough development time of mixogram.

[d] Least significant difference ($P < 0.05$).

TABLE IV
Effect of Break-Roll Differential (BRD)[a] on Spaghetti Quality[b]

BRD	DSS (g)	Hunter *L*	Hunter *b*	CL (%)	CW (g)	CF (g-cm)
1.5:1	34.4	59.35	43.95	6.0	32.0	5.3
2.5:1	34.9	59.50	43.77	5.8	32.1	5.3
3.5:1	33.0	57.66	41.64	6.0	32.0	5.5
LSD[c]	ns[d]	0.30	0.85	ns	ns	ns

[a] BRD averaged across cultivars.

[b] DSS = dry spaghetti strength, CL = cooking loss, CW = cooked weight, CF = cooked firmness.

[c] Least significant difference ($P < 0.05$).

[d] Not significant.

For semolina quality, break-roll differential by cultivar interaction was only significant for bran specks. The effect of break-roll differential on semolina ash content, protein content, color, mixogram parameters, and starch damage was independent of cultivar. Interactions between break-roll differential and cultivar and drying temperature were not significant for any of the spaghetti quality factors evaluated. Therefore, the effect of break-roll differential on spaghetti quality was independent of cultivar and spaghetti drying temperature.

In this study, the slow roll of the break-roll pair was adjusted to give the desired break-roll differential against a fixed fast roll speed of 350 rpm. Break-roll differential was decreased by increasing rpm of the slow roll. Further studies are needed (within commercial milling) to study the opposite effect, whereby increasing the fast roll against a fixed slow roll causes the roll differential to increase.

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