Physical and Cooking Quality of Spaghetti Made from Whole Wheat Durum

Frank A. Manthey[1,2] and Anton L. Schorno[1]

ABSTRACT

Cereal Chem. 79(4):504–510

The effects of cultivar on dough properties of ground whole wheat durum, and the effects of cultivar and drying temperature on the physical and cooking quality of spaghetti made from semolina and whole wheat were evaluated. Rankings of cultivars based on dough properties were similar for whole wheat and semolina. Dough made from whole wheat was weak and had poor stability. Whole wheat spaghetti had a rough reddish brown surface compared with the very smooth, translucent yellow color of spaghetti made from semolina. The reddish brown color of whole wheat spaghetti was enhanced by high-temperature drying (70°C). Mechanical strength and cooking quality of spaghetti made from ground whole wheat or semolina varied with cultivar and with drying temperature. Compared with spaghetti made from semolina, whole wheat spaghetti had lower mechanical strength and cooked firmness and had greater cooking loss. Mechanical strength of whole wheat spaghetti was lower when dried at high temperature (70°C) than at low temperature (40°C). Conversely, the mechanical strength of spaghetti made from semolina was greater when dried at high temperature than at low temperature. Whole wheat and traditional spaghetti dried at high temperature had lower cooking losses than spaghetti dried at low temperature. When overcooked 6 min, firmness of spaghetti made from semolina or whole wheat was greater when dried at high temperature than at low temperature.

Pasta made from semolina is a good source of complex carbohydrates. Pasta contains relatively high amounts of resistant starch and is low in fat (Seibel 1996). When milling durum wheat into semolina, the bran and germ are removed. Bran and germ remaining in the semolina are considered contaminants. However, bran and germ are rich in vitamins, minerals (Peterson et al 1986), natural antioxidants (Onyeneho and Hettiarachchy 1992), and dietary fiber (Seibel 1996). Vitamins and minerals are important nutritional components, and antioxidants and dietary fiber have been associated with various health benefits (Hegarty 1995). Thus, making pasta from ground whole wheat would increase the nutrition of pasta and the health benefits for consumers.

Whole wheat durum meal is produced by grinding clean grain with a disc, hammer, or stone mill. Because durum mills are designed to produce semolina, some whole wheat is produced by regrinding the bran and germ removed during durum milling and blending them back into the semolina.

Whole wheat is a less homogenous mixture than semolina. The presence of bran and germ in the semolina can physically interfere with dough development. Bran and germ particles result in discontinuity within the gluten matrix. The general deterioration in functional properties of dough containing bran is well documented in literature (Bruinsma et al 1978; D'Appolonia and Youngs 1978; Özboy and Köksel 1997; Zhang and Moore 1997). The presence of bran particles physically interferes with dough development, resulting in weak dough properties.

Information is lacking concerning the effect of cultivar on whole wheat dough properties. Kunerth and Youngs (1984) reported that composition of bran from durum wheat varied with cultivar and growing conditions. Özboy and Köksel (1997) described bread wheat cultivar 'Gerek' that, when coarsely ground did not adversely affect dough strength but strengthened farinogram mixing properties. The strengthening effect was observed at bran addition levels of 5 and 10%.

The use of bran or whole wheat affects the quality of end-use products. The effects of bran on bread quality have been well documented. Wheat bran reduced loaf volume, increased crumb density, and reduced crumb softness (Pomeranz et al 1977; Lai et al 1989; Gan et al 1992; Özboy and Köksel 1997). Crust and crumb are darker for bread made with wheat bran than without (Pomeranz et al 1977). The reduction in loaf volume has been attributed to a decrease in gas retention by dough containing wheat bran. Gan et al (1992) reported that nonendosperm components induced serious structural distortion of gas cells that resulted in poor crumb texture.

Several reports have been published concerning the quality of spaghetti made with whole wheat or bran-semolina (Kordonowy and Youngs 1985; Sahlström et al 1993; Edwards et al 1995). These reports indicated that spaghetti made from whole wheat or bran-semolina was darker and had poorer cooking quality than spaghetti made from semolina. The whole wheat or bran-semolina spaghetti evaluated in these studies were dried at low temperature. A review of the available literature did not find any mention of the effect of high-temperature drying on appearance, mechanical strength, or cooking quality of whole wheat or bran-semolina spaghetti.

High-temperature drying generally results in improved cooking properties such as increased cooked firmness, greater color intensity, decreased stickiness, and reduced cooking loss (Wyland and D'Appolonia 1982; D'Egidio et al 1990; Grant et al 1993; Malcolmson et al 1993; Novaro et al 1993) compared with spaghetti dried at low temperatures. This research was conducted to determine the effects of cultivar on dough and extrusion properties, and the effects of cultivar and drying temperature on appearance, mechanical strength, and cooking quality of whole wheat spaghetti.

MATERIALS AND METHODS

Sample Preparation

Samples of durum cultivars 'Ben', 'Lebsock', and 'Renville' and a bulk sample containing a mixture of cultivars were obtained from grain grown at the North Dakota Agricultural Experiment Station, Williston, ND, in 2000. Ben and Renville represent 51% of the hectares planted to durum wheat in North Dakota (Hartwig and Meyer 2001). Lebsock, released in 1999, has the potential to replace Renville in hectares planted.

Wheat samples milled into semolina were cleaned, tempered to 17.5% moisture, and milled in an experimental mill fitted with two laboratory-scale purifiers (Bühler-Miag, Minneapolis, MN). Wheat samples ground into whole wheat were cleaned and then ground using a bulk coffee grinder (Bunn, Springfield, IL) at the finest grind setting. The grain was fed slowly into the coffee grinder to avoid high temperatures during grinding.

Granulation of the semolina and ground whole wheat samples were measured from the % overs (w/w) of a Ro-Tap mechanical shaker (100 g of sample for 5 min) with U.S. Standard sieves 30, 40, 60, 80, and 100 (600, 425, 250, 180, and 149 µm, respectively). Each sample was evaluated in triplicate.

[1] Assistant professor and graduate research assistant, respectively, Department of Cereal and Food Sciences, North Dakota State University, Fargo, ND 58105.

[2] Corresponding author. E-mail: Frank.Manthey@ndsu.nodak.edu. Phone: 701-231-6356. Fax: 701 231-7723.

Publication no. C-2002-0604-01R.

© 2002 American Association of Cereal Chemists, Inc.

Mixograph

Dough strength was measured using a mixograph (National Mfg., Lincoln, NE) according to Approved Method 54-40A (AACC 2000).

Sample Analysis

AACC Approved Methods were used to determine ash (Method 08-01), protein (N × 5.7) (Method 46-30), falling number (Method 56-81B), wet gluten and gluten index (Method 38-12), and starch damage (Method 76-31) on semolina and whole wheat.

Extrusion

Semolina and whole wheat (900 g) were hydrated to 32–33% moisture and extruded as spaghetti using a semicommercial laboratory extruder (Demaco, Melbourne, FL). Extrusion temperature was 45°C, mixing chamber vacuum was 46 cm of Hg, and auger extrusion speed was 25 rpm. 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 dried spaghetti was measured with a colorimeter (model CR310, Minolta Corp., Ramsey, NJ). Color readings were expressed by Hunter values for *L*, *a*, and *b*. *L* values measure black to white (0–100); *a* values measure redness when positive; and *b* values measure yellowness when positive. Mechanical strength of dry spaghetti was measured by the work (g·cm) required to break one strand of dried spaghetti. Mechanical strength was measured on four individual strands per sample using a texture analyzer (TA-XT2, Texture Technologies Corp., Scarsdale, NY). Diameter of dried spaghetti was determined by taking measurements at the midpoint of eight individual strands per sample.

Spaghetti (10 g) was cooked in 300 mL of boiling water for 12 min. Cooking loss (% total solids weight) was measured by evaporating cooking water to dryness overnight in a forced-air oven at 110°C. Cooked firmness was measured using the texture analyzer. Cooked firmness was determined by measuring the work (g·cm) required to shear five cooked strands of spaghetti. Optimum cooking time was determined using Approved Method 66-50 (AACC 2000). Optimum cooking time corresponds to the disappearance of white in the central core of the spaghetti. Cooking tests were conducted at optimum cooking time and 6 min after optimum cooking time (overcooked).

Scanning Electron Microscopy

Scanning electron microscopy was conducted at the Electron Microscopy Center located at North Dakota State University, Fargo. Samples were mounted on aluminum mounts with silver paint. After attachment to the mounts, the samples were coated with gold-palladium using a Balzars SCD030 sputter coater. The specimens were examined and photographed using a JEOL JSM-6300 scanning electron microscope.

Statistical Analysis

The experiment consisted of durum samples (three cultivars and one bulk blend), milled products (semolina and whole wheat), and drying temperatures (40 and 70°C). The experimental design was a randomized complete block with a split-plot arrangement. Whole plots were drying temperatures and subplots were a factorial arrangement of cultivar and milled product. All treatments were replicated and each measurement on a treatment was done in duplicate unless otherwise stated. All data were subjected to an analysis of variance using the Statistical Analysis System (SAS Institute, Cary, NC). Means were separated by Fisher's protected least significant difference ($P < 0.05$).

RESULTS AND DISCUSSION

Whole wheat was ground to a granulation similar to that of the semolina (Table I). Particle size affects the rate of hydration of the milled product during pasta processing (Dalbon et al 1996). Incomplete hydration of semolina or ground whole wheat would result in white specks in the spaghetti. White specks are starchy areas of little or no gluten development. Thus, white specks would affect the appearance, mechanical strength, and cooking quality of spaghetti.

Proximate analysis of both semolina and whole wheat are shown in Table II. The cultivar by milled product interaction was not significant for ash content, protein content, wet gluten content, falling number value, or starch damage. Ash and protein contents were greater with whole wheat than with semolina (Table II). The bran layer is rich in ash and protein (Kunerth and Youngs 1984; Pomeranz 1988), so removing bran during milling would lower protein and ash contents in the semolina. Ash content was greatest for the bulk blend, intermediate for Ben and Lebsock, and lowest for Renville.

TABLE I
Particle Size Distribution (%) of Semolina and Ground Whole Wheat[a]

	Mesh Size, μm					
Milled Product	**600**	**425**	**250**	**180**	**149**	**<149**
Semolina	0	5	46	33	4	12
Ground whole wheat	1	8	49	24	5	13

[a] Averaged over durum cultivar or sample.

TABLE II
Proximate Analysis (14%, wb) of Semolina and Ground Whole Wheat

Source	Ash (%)	Protein (%)	Wet Gluten Content (%)	Falling Number (sec)
Cultivar or sample[a]				
Ben	1.04	15	42	571
Lebsock	1.01	14.3	40	576
Renville	0.99	14.3	40	537
Bulk blend	1.27	15.4	43	519
LSD[b]	0.02	0.1	2	38
Milled product[c]				
Semolina	0.65	14.4	42	639
Ground wholewheat	1.50	15.1	41	463
LSD	0.01	0.1	ns[d]	27

[a] Values averaged over milled product.
[b] Least significant difference ($P < 0.05$).
[c] Values averaged over cultivar or sample.
[d] Not significant.

Ben and the bulk blend had higher protein and wet gluten contents than did Renville or Lebsock. Wet gluten content was similar for semolina and whole wheat (Table II), which indicates that not all proteins in the bran material were storage proteins (Teller and Teller 1936). Ground whole wheat generally is not used to determine gluten index (AACC Approved Method 38-12). Bran or germ particles in ground whole wheat could accumulate and block the screen used to determine gluten index, which would result in inflated gluten index values.

All cultivars had high falling number values indicating sound wheat with no preharvest sprouting. Falling number was higher for semolina than for whole wheat. α-Amylase is concentrated in the germ and aleurone layers (Meredith and Pomeranz 1985). Removing the germ and the aleurone layer during milling decreases α-amylase content, which results in increased falling number values for semolina (Dexter et al 1990). The effect of milling on falling number depends on the amount of α-amylase present in the endosperm (Posner and Hibbs 1997).

Starch damage did not differ with cultivar but was greater with ground whole wheat (3.3%) than with semolina (2.9%). Damaged starch can absorb four to five times more water than intact starch (Milatovi• and Mondelli 1991). A high level of starch damage could affect hydration and subsequent gluten development during pasta processing. Starch damage has also been associated with increased stickiness of cooked pasta (Grant et al 1993). Although statistically different, the difference in starch damage between ground whole wheat and semolina probably is not great enough to have an effect on pasta processing or cooking quality.

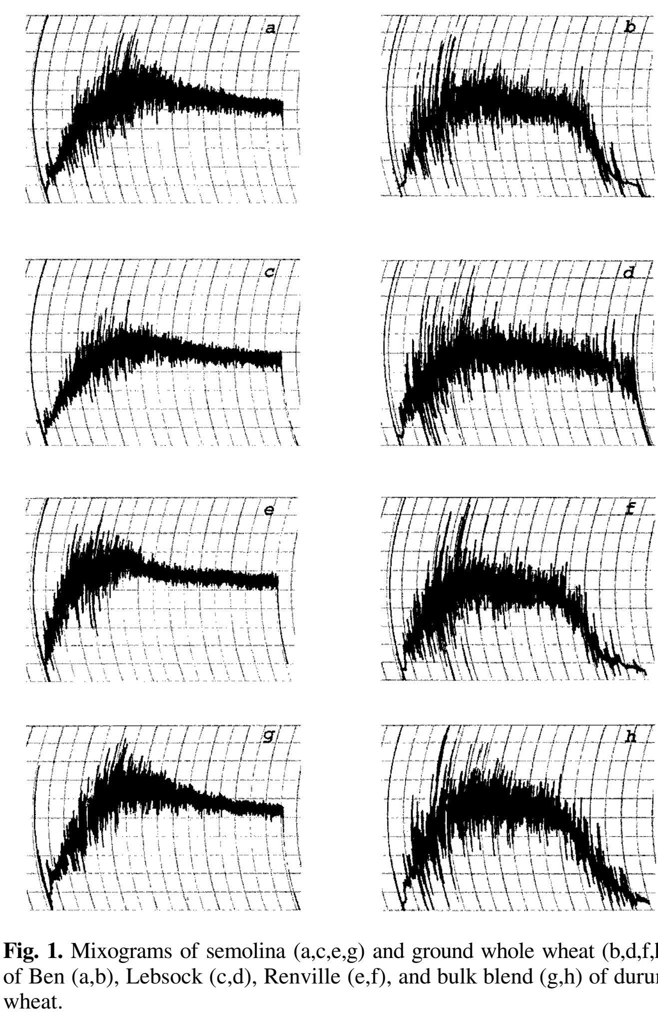

Fig. 1. Mixograms of semolina (a,c,e,g) and ground whole wheat (b,d,f,h) of Ben (a,b), Lebsock (c,d), Renville (e,f), and bulk blend (g,h) of durum wheat.

Mixograph

Cultivars differed in dough strength; Ben and the bulk blend were stronger than Lebsock and Renville (Fig. 1). Regardless of cultivar, mixograms of ground whole wheat had lower peak heights and greater peak widths than the corresponding mixograms of semolina.

Mixograph dough development time (the time required for the mixogram curve to reach maximum height) was similar for semolina and ground whole wheat, regardless of cultivar (Fig. 1). The effect of bran on dough development time has been inconsistent (Pomeranz et al 1977). Wheat bran has been reported to increase (Kordonowy and Youngs 1985; Zhang and Moore 1997), decrease (D'Appolonia and Youngs 1978), and have no effect on dough development time (Sahlström et al 1993).

Based on mixogram curves, whole wheat Lebsock had greater dough stability than Ben, Renville, or the bulk blend (Fig. 1). Dough stability of ground whole wheat was poor for Ben, Renville, and the bulk blend, as evidenced by the rapid decline of the mixogram curves after 5.5 to 6 min. Dough stability indicates the time during which the dough resists mechanical action without undergoing a change in consistency (Kovacs et al 1997). Bruinsma et al (1978) reported similar results for mixograms of 100% ground whole meal from soft wheat. They reported rapid decline in dough stability after 4–5 min of mixing. At the point of rapid decline, the hydrated ground whole wheat began to accumulate along the sides of the mixing bowl. Lack of dough stability or tolerance to overmixing could be related to the dilution of semolina by the bran and germ. Fewer storage proteins are available to form a gluten matrix and there are more bran particles to physically interfere with the gluten matrix. Other researchers have reported that dough stability decreases with increased bran concentration (Özboy and Köksel 1997; Zhang and Moore 1997).

Appearance

Whole wheat spaghetti had a rough surface and a reddish brown color compared with the very smooth, translucent yellow semolina pasta. Cultivar by milled product by drying temperature interaction, and cultivar by drying temperature interaction were not significant, but the cultivar by milled product interaction and the drying temperature by milled product interaction were significant for brightness (*L* value), redness (*a* value), and yellowness (*b* value). Brightness and yellowness were lower and redness was higher for spaghetti made from ground whole wheat than from semolina (Table III). Small differences in brightness, redness, and yellowness occurred among cultivars. The poorest color for both semolina and ground whole wheat occurred with the bulk sample.

Brightness of semolina spaghetti was increased slightly, and brightness of whole wheat spaghetti was decreased when dried at 70°C as compared with 40°C (Table III). Drying temperature did not affect redness or yellowness of spaghetti made from semolina. High-temperature drying has been associated with improved pasta color (Wyland and D'Appolonia 1982; Aktan and Khan 1992). However, whole wheat spaghetti was more red and less bright and yellow when dried at 70°C than at 40°C. Thus, high-temperature drying improved or had no effect on the color of spaghetti made from semolina, but it diminished the color of whole wheat spaghetti.

There were no significant interactions involving cultivar, milled product, or drying temperature for spaghetti diameter. Only the main effects of cultivar and milled product were significant for spaghetti diameter. Whole wheat spaghetti had a diameter ≤0.04 mm larger than the semolina spaghetti (data not presented). This small increase in diameter is attributed to the rough surface of the whole wheat spaghetti. Small bran particles could be seen protruding from the surface of the whole wheat spaghetti. Small differences (0.02 mm) in spaghetti strand diameter were measured among cultivars. Drying temperature did not affect the diameter of spaghetti strands. This indicates that the spaghetti strands made from ground whole wheat possessed sufficient dough strength that they did not stretch while hanging on the drying rods.

Mechanical Strength

Cultivar by milled product by drying temperature interaction and cultivar by drying temperature interaction were not significant, but the cultivar by milled product interaction and drying temperature by milled product interaction were significant for mechanical strength of spaghetti. Mechanical strength was greatest with spaghetti made from semolina milled from Ben (1.75 g·cm) and Lebsock (1.75 g·cm), intermediate from Renville (1.47 g·cm), and lowest from the bulk blend (1.13 g·cm); values were averaged over drying temperature. The mechanical strength of spaghetti made from ground whole wheat was greatest when ground from the bulk blend (0.58 g·cm), intermediate from Ben (0.56 g·cm), and lowest from Lebsock (0.51 g·cm) and Renville (0.52 g·cm); values were averaged over drying temperature. The level of mechanical strength for whole wheat spaghetti might be related to wet gluten content. Wet gluten content was greater for Ben and the bulk blend than for Lebsock and Renville (Table II). Whole wheat spaghetti made from Ben and the bulk blend had more gluten available to surround the bran-germ particles, which probably resulted in greater mechanical strength than that found with whole wheat spaghetti made from Lebsock and Renville. Interestingly, there was no relationship between mechanical strength of semolina spaghetti and wet gluten content. The mechanical strength of spaghetti made from semolina was greatest with Ben and lowest with the bulk blend sample.

Drying temperature had opposing effects on mechanical strength of spaghetti made from ground whole wheat and semolina. The mechanical strength of whole wheat spaghetti was lower when dried at high temperature than at low temperature (0.49 and 0.59 g·cm, respectively), while the mechanical strength of spaghetti made from semolina was greater when dried at high temperature than at low temperature (1.58 and 1.47 g·cm, respectively); values were averaged over cultivars. The decrease in mechanical strength of whole wheat spaghetti dried at high temperature might be due to a slight contraction in the gluten matrix, which could accentuate the localized disruption of gluten matrix by bran and germ particles.

The poor mechanical strength of whole wheat spaghetti can be attributed to physical interference of the gluten matrix by bran-germ particles. Scanning electron micrographs show bran particles disrupting the gluten matrix of dry whole wheat spaghetti (Fig. 2c). The absence of bran particles can be seen in the electron micrographs of spaghetti made from semolina (Fig. 2a,b). Bran particles interfered with the gluten network and did not appear to be in close association with the gluten matrix, as evidenced by the space around bran particles (Fig. 2c). Figure 2d shows a bran fragment containing

TABLE III
Color of Spaghetti Made from Semolina (S) and Ground Whole Wheat (W) as Affected by Cultivar and Drying Temperature

	Color Values[a]					
	L		*a*		*b*	
Source	**S**	**W**	**S**	**W**	**S**	**W**
Cultivar or sample[b]						
Ben	57.2	37.0	1.98	8.78	28.0	14.5
Lebsock	57.4	37.7	1.90	8.76	28.5	14.9
Renville	57.6	37.7	1.67	8.29	28.1	14.9
Bulk blend	55.1	36.3	2.20	8.32	27.1	14.3
LSD[c]	0.2	0.2	0.13	0.13	0.1	0.1
Drying temperature[d]						
40°C	56.7	37.7	1.94	8.38	27.9	14.8
70°C	56.9	36.7	1.93	8.70	27.9	14.6
LSD[c]	0.2	0.2	0.09	0.09	0.1	0.1

[a] *L* values measure black to white (0–100); *a* values measure redness when positive; and *b* values measure yellowness when positive.
[b] Values averaged over drying temperature.
[c] Least significant difference ($P < 0.05$).
[d] Values averaged over cultivar or sample.

TABLE IV
Optimum Cooking Time (min) and Firmness (g·cm) of Spaghetti Made from Semolina and Ground Whole Wheat When Cooked to Optimum

Milled Product	Drying Temperature (°C)	Time[a]	Firmness[a]	Cultivar or Sample	Firmness[b]
Semolina	40	10.75	8.4	Ben	8.3
	70	10.75	8.4	Lebsock	7.8
Whole wheat	40	10.50	8.0	Renville	7.9
	70	10.00	7.5	Bulk blend	8.2
LSD[c]		0.15	0.2		0.2

[a] Values averaged over cultivar.
[b] Values averaged over milled product and drying temperature.
[c] Least significant difference ($P < 0.05$).

TABLE V
Cooking Loss (%) and Firmness (g·cm) of Spaghetti Made from Semolina (S) and Ground Whole Wheat (W) After 6 min of Overcooking

	Cooking Loss				Cooked Firmness	
	Milled Product[a]		Drying Temperature[b]		Milled Product[a]	
Cultivar or Sample	**S**	**W**	**40°C**	**70°C**	**S**	**G**
Ben	6.5	8.7	8.1	7.0	6.8	5.8
Lebsock	6.5	8.5	7.8	7.2	6.4	5.6
Renville	6.4	8.5	8.1	6.8	6.6	5.6
Bulk blend	6.5	8.9	8.0	7.1	6.6	6.2
LSD[c]	0.2	0.2	0.2	0.2	0.2	0.2

[a] Values averaged over drying temperature.
[b] Values averaged over milled product
[c] Least significant difference ($P < 0.05$).

aleurone cells on the surface of whole wheat spaghetti. Even though spaghetti was weakened by the presence of bran and germ, checking had not occurred after 10 months of storage under ambient conditions.

Optimum Cooking Time

Cultivar by milled product by drying temperature interaction, cultivar by milled product interaction, and cultivar by drying temperature interaction were not significant, but the drying temperature by milled product interaction was significant for optimum cooking time. Optimum cooking time did not vary with cultivar. Optimum cooking time was longer for spaghetti made from semolina than from ground whole wheat (Table IV). The physical disruption of the gluten matrix by the bran and germ particles (Fig. 2c,d) provided a path for water absorption into the whole wheat spaghetti strand that reduced cooking time. Drying temperature did not affect optimum cooking time for spaghetti made with semolina. However, optimum cooking time was greater for whole wheat spaghetti dried at 70°C than at 40°C.

Cooking Loss

When cooked to optimum, none of the interactions among or between cultivar, milled product, or drying temperature were significant, nor did cooking loss vary with cultivar. When overcooked 6 min, cultivar by milled product by drying temperature interaction, and milled product by drying temperature interaction were not significant, but cultivar by milled product interaction and cultivar by drying temperature interaction were significant for cooking loss.

When cooked to optimum, cooking losses were greater from spaghetti made with whole wheat (7%) than with semolina (5.3%); values were averaged over cultivar and drying temperature. Similarly, cooking losses were greater from spaghetti made with whole wheat than with semolina, when overcooked 6 min (Table V). The greater cooking loss from spaghetti made with ground whole wheat than with semolina is due in part to disruptions in the gluten matrix by bran-germ particles (Fig. 2c,d), along with the presence of water-soluble components within the bran and aleurone layers (Kunerth and Youngs 1984). The disruption in gluten matrix, along with space between bran particle and matrix in dried spaghetti (Fig. 2c,d), could promote water absorption and expose starch granules to swelling and rupture. Disruptions in the gluten matrix led to greater cooking losses as bran particles sloughed off the spaghetti into the cooking water. Inspection of the cooking water revealed that bran particles were suspended in the water used to cook the whole wheat spaghetti.

When overcooked 6 min, cultivars did not vary in cooking loss from spaghetti made from semolina (Table V). However, cooking losses were greatest from spaghetti made from the whole wheat bulk blend, intermediate from whole wheat Ben, and least from whole wheat Lebsock or Renville. These cultivar differences cannot be explained by differences in protein or wet gluten contents because Ben and the bulk blend contained more protein and wet gluten than did Lebsock or Renville (Table II). The cultivar differences in cooking loss from whole wheat spaghetti might be due to differences among cultivars in the amount of soluble components found in the bran and aleurone layers. Kunerth and Youngs (1984) reported that, for five durum cultivars, the starch content of bran varied from 14.9 to 17% and water-soluble nonstarch polysaccharides varied from 0.4 to 0.8%.

When cooked to optimum, cooking losses were greater for spaghetti dried at low temperatures (6.5%) than at high (5.8%) temperatures; values were averaged over cultivar and milled product. Similarly, cooking losses were greater with spaghetti dried at 40°C than at 70°C when overcooked 6 min (Table V). The effect of cultivar on cooking loss varied with the temperature used to dry the spaghetti.

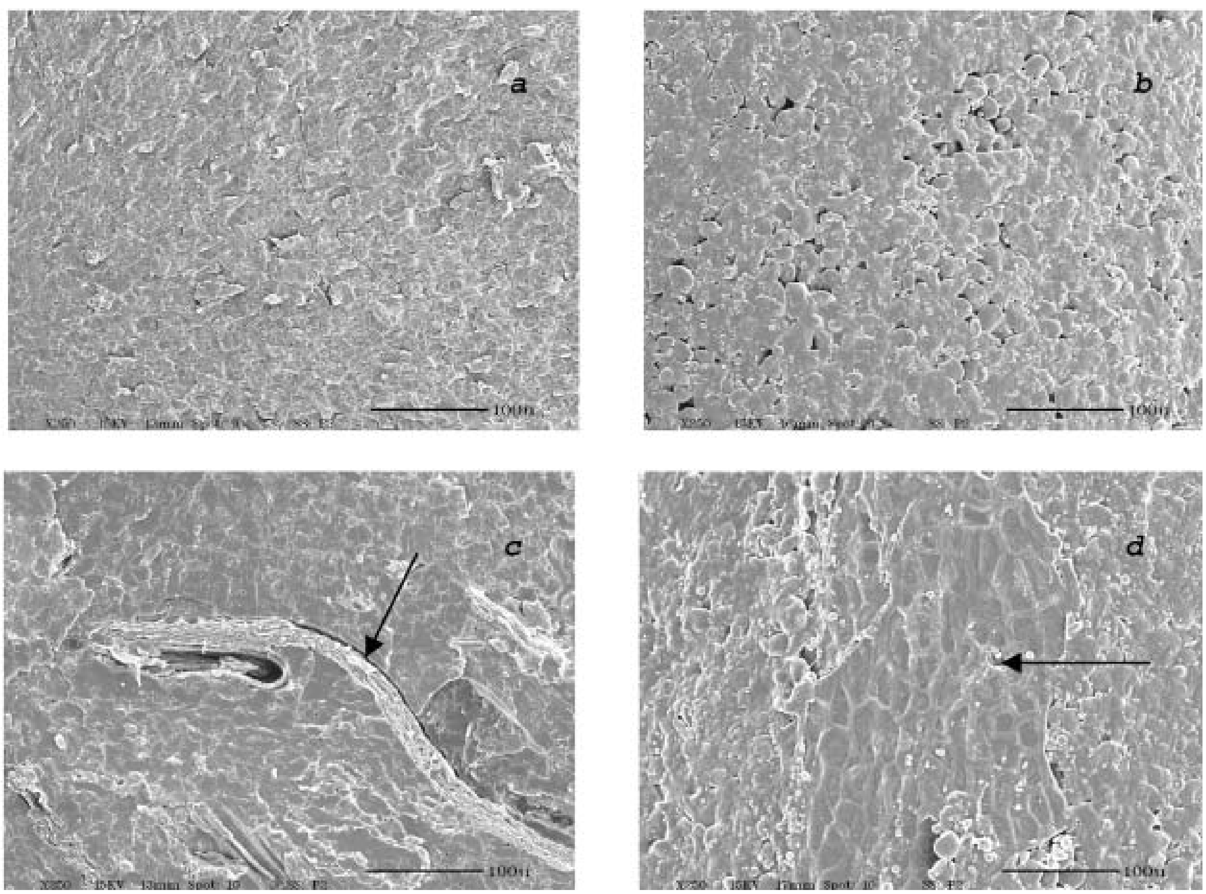

Fig. 2. Scanning electron micrographs of cross-section (a,c) and surface (b,d) of spaghetti made from semolina (a,b) and ground whole wheat (c,d) and dried at high temperature (70°C). Magnification was 250× and bar = 100 µm. Note space between bran particle and gluten matrix (c) and aleurone cells on the spaghetti surface (d).

For example, spaghetti dried at 40°C had the greatest cooking loss when made from Renville or Ben and the least cooking loss when made from Lebsock. Conversely, spaghetti dried at 70°C had the greatest cooking loss when made from Lebsock and the least cooking loss when made from Renville. Drying at high temperature (≥60°C) generally results in decreased cooking loss (D'Egidio et al 1990; Aktan and Khan 1992; Grant et al 1993; Malcolmson et al 1993; Novaro et al 1993). High-temperature drying strengthens the gluten matrix, which protects starch granules from rupturing during cooking. Furthermore, high-temperature drying reduces water permeability and causes small changes in the packing and arrangement of starch granules, contributing to reduced cooking losses and increased cooked firmness (Vansteelandt and Delcour 1998; Yue et al 1999).

Cooking loss of ≤8% is considered acceptable for good quality pasta (Dick and Youngs 1988). When cooked to optimum, cooking losses from spaghetti made from semolina or ground whole wheat were all <8%. However when overcooked 6 min, spaghetti made from ground whole wheat had cooking losses >8%, regardless of drying temperature.

Cooked Firmness

When cooked to optimum, cultivar by milled product by drying temperature interaction, cultivar by drying temperature interaction, and cultivar by milled product interaction were not significant, but milled product by drying temperature interaction was significant for cooked firmness. When overcooked 6 min, cultivar by milled product by drying temperature interaction, cultivar by drying temperature interaction, and milled product by drying temperature interaction were not significant, but cultivar by milled product interaction was significant for cooked firmness.

Cooked firmness was greater for spaghetti made from semolina than from whole wheat, whether cooked to optimum or overcooked 6 min (Tables IV and V). Whole wheat pasta was reported to have lower cooked firmness than traditional semolina pasta (Sahlström et al 1993; Edwards et al 1995). When cooked to optimum, firmness was greater for spaghetti made from Ben and the bulk blend than from Lebsock or Renville. Firmness of spaghetti cooked to optimum appears to be related to protein and wet gluten contents of the cultivars (Table II). Cooking quality improves with increased protein content (Matsuo et al 1972; D'Egidio et al 1990; Novaro et al 1993). The lack of a significant cultivar by milled product interaction for cooked firmness indicates that the cultivar effect was the same for spaghetti made from semolina or whole wheat. However, when overcooked 6 min, firmness was greatest for spaghetti made with semolina from Ben, intermediate with semolina from Renville and the bulk sample, and least with semolina from Lebsock (Table V). For whole wheat spaghetti, cooked firmness was greatest with the bulk sample, intermediate with Ben, and least with Renville or Lebsock.

When cooked to optimum, drying temperature did not affect the cooked firmness of spaghetti made from semolina. However, cooked firmness was lower for whole wheat spaghetti dried at high temperature than at low temperature (Table IV). Typically, high-temperature drying enhances cooked firmness of spaghetti (Wyland and D'Appolonia 1982; Aktan and Khan 1992). The high protein content of semolina (14.4%) probably masked the effect of high-temperature drying on cooked firmness of spaghetti made with semolina (Tables II and IV). The effect of drying temperature on cooked firmness of spaghetti made with whole wheat appears to be related to cooking time. Optimum cooking time was 30 sec longer for whole wheat spaghetti dried at 70°C than at 40°C (Table IV). The additional 30 sec of cooking for whole wheat spaghetti dried at 70°C might have resulted in the outer portion of the spaghetti strand becoming overcooked. When overcooked 6 min, firmness was greater with high-temperature drying (6.3 g·cm) than with low-temperature drying (6.0 g·cm); values were averaged over cultivar and milled product. The lack of any significant interactions involving drying temperature indicate that drying temperature had the same effect on firmness, regardless of cultivar or milled product.

CONCLUSIONS

These results indicate the importance of the gluten matrix in mechanical strength and cooking quality of pasta. Bran and germ particles in ground whole wheat interfered with the continuity of the gluten matrix. This interference caused weakening of dough and reduced the mechanical strength and cooking quality of the whole wheat spaghetti. Mechanical strength and cooked firmness of spaghetti made from ground whole wheat or semolina varied with cultivar and with drying temperature. Content of protein and wet gluten seemed to relate positively with mechanical strength and cooking quality. Whole wheat spaghetti dried at low temperature (40°C) had higher cooking loss but had better overall appearance, mechanical strength, and cooked firmness than whole wheat spaghetti dried at high temperature (70°C).

ACKNOWLEDGMENTS

The scanning electron microscopy was conducted by personnel at the Electron Microscopy Center, North Dakota State University, Fargo.

LITERATURE CITED

Aktan, B., and Khan, K. 1992. Effect of high-temperature drying of pasta on quality parameters and on solubility, gel electrophoresis, and reverse-phase high-performance liquid chromatography of protein components. Cereal Chem. 69:288-295.

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Methods 38-12, 46-30, 54-40A, 56-81B, 66-50, 76-31. The Association: St. Paul, MN.

Bruinsma, B. L., Anderson, P. D., and Rubenthaler, G. L. 1978. Rapid method to determine quality of wheat with the mixograph. Cereal Chem. 55:732-735.

Dalbon, G., Grivon, D., and Pagani, M. A. 1996. Pasta: Continuous manufacturing process. Pages 13-58 in: Pasta and Noodle Technology. J. E. Kruger, R. B. Matsuo, and J. W. Dick, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

D'Appolonia, B. L., and Youngs, V. L. 1978. Effect of bran and high-protein concentrate from oats on dough properties and bread quality. Cereal Chem. 55:736-743.

D'Egidio, M. G., Mariani, B. M., Nardi, S., Novaro, P., and Cubadda, R. 1990. Chemical and technological variables and their relationships: A predictive equation for pasta cooking quality. Cereal Chem. 67:275-281.

Dexter, J. E., Matsuo, R. R., and Kruger, J. E. 1990. The spaghetti-making quality of commercial durum wheat samples with variable α-amylase activity. Cereal Chem. 67:405-412.

Dick, J. W., and Youngs, V. L. 1988. Evaluation of durum wheat semolina and pasta in the United States. Pages 237-248 in: Durum Wheat: Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

Edwards, N. M., Biliaderis, C. G., and Dexter, J. E. 1995. Textural characteristics of wholewheat pasta and pasta containing non-starch polysaccharides. J. Food Sci. 60:1321-1324.

Gan, Z., Galliard, T., Ellis, P. R., Angold, R. E., and Vaughan, J. G. 1992. Effect of the outer bran layers on the loaf volume of wheat bread. J. Cereal Sci. 15:151-163.

Grant, L. A., Dick, J. W., and Shelton, D. R. 1993. Effects of drying temperature, starch damage, sprouting, and additives on spaghetti quality characteristics. Cereal Chem. 70:676-684.

Hartwig, D., and Meyer, B. 2001. North Dakota Agricultural Statistics 2001. Agric. Statistics No. 70. ND Agric. Statistics Service: Fargo, ND.

Hegarty, V. 1995. Nutrition, Food, and the Environment. Am. Assoc. Cereal Chem.: St. Paul, MN.

Kordonowy, R. K., and Youngs, V. L. 1985. Utilization of durum bran and its effect on spaghetti. Cereal Chem. 62:301-308.

Kovacs, M. I. P., Poste, L. M., Butler, G., Woods, S. M., Leisle, D., Noll, J. S., and Dahlke, G. 1997. Durum wheat quality: Comparison of chemical and rheological screening tests with sensory analysis. J. Cereal Sci. 25:65-75.

Kunerth, W. H., and Youngs, V. L. 1984. Effect of variety and growing year on the constituents of durum bran fiber. Cereal Chem. 61:350-352.

Lai, C. S., Hoseney, R. C., and Davis, A. B. 1989. Effects of wheat bran in breadmaking. Cereal Chem. 66:217-219.

Malcolmson, L. J., Matsuo, R. R., and Balshaw, R. 1993. Effects of drying temperature and farina blending of spaghetti quality using

response surface methodology. Cereal Chem. 70:1-7.
Matsuo, R. R., Bradley, J. W., and Irvine, G. N. 1972. Effect of protein content on the cooking quality of spaghetti. Cereal Chem. 49:707-711.
Meredith, P., and Pomeranz, Y. 1985. Sprouted grain. Pages 239-320 in: Advances in Cereal Science and Technology, Vol. VII. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
Milatovi•, L., and Mondelli, G. 1991. Pasta Technology Today. Chiriotti Editori: Pinerolo, Italy.
Novaro, P., D'Egidio, M. G., Mariani, B. M., and Nardi, S. 1993. Combined effect of protein content and high-temperature drying systems on pasta cooking quality. Cereal Chem. 70:716-719.
Onyeneho, S. N., and Hettiarachchy, N. S. 1992. Antioxidant activity of durum wheat bran. J. Agric. Food Chem. 40:1496-1500.
Özboy, Ö., and Köksel, H. 1997. Unexpected strengthening effects of a coarse wheat bran on dough rheological properties and baking quality. J. Cereal Sci. 25:77-82.
Peterson, C. J., Johnson, V. A., and Mattern, P. J. 1986. Influence of cultivar and environment on mineral and protein concentrations of wheat flour, bran, and grain. Cereal Chem. 63:183-186.
Pomeranz, Y. 1988. Chemical composition of kernel structures. Pages 97-157 in: Wheat Chemistry and Technology, Vol I. 3rd Ed. Y. Pomeranz, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
Pomeranz, Y., Shogren, M. D., Finney, K. F., and Bechtel, D. B. 1977. Fiber in breadmaking—Effects on functional properties. Cereal Chem. 54:25-41.
Posner, E. S., and Hibbs, A. N. 1997. Wheat Flour Milling. Am. Assoc. Cereal Chem.: St. Paul, MN.
Sahlström, S., Mosleth, E., Baevre, A. B., Gloria, H., and Fayard, G. 1993. Influence of starch, gluten proteins and extraction rate on bread and pasta quality. Carbohydr. Polym. 21:169-175.
Seibel, W. 1996. Future trends in pasta products. Pages 331-349 in: Pasta and Noodle Technology. J. E. Kruger, R. B. Matsuo, and J. W. Dick, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
Teller, G. L., and Teller, W. K. 1932. A study of proteins of wheat bran. Cereal Chem. 9:560-572.
Vansteelandt, J., and Delcour, J. A. 1998. Physical behavior of durum wheat starch (*Triticum durum*) during industrial pasta processing. J. Agric. Food Chem. 46:2499-2503.
Wyland, A. R., and D'Appolonia, B. L. 1982. Influence of drying temperature and farina blending on spaghetti quality. Cereal Chem. 59:199-201.
Yue, P., Rayas-Duarte, P., and Elias, E. 1999. Effect of drying temperature on physicochemical properties of starch isolated from pasta. Cereal Chem. 76:541-547.
Zhang, D., and Moore, W. R. 1997. Effect of wheat bran particle size on dough rheological properties. J. Sci. Food Agric. 74:490-496.

[Received October 24, 2001. Accepted February 28, 2002.]