Effects of Drying Temperature, Starch Damage, Sprouting, and Additives on Spaghetti Quality Characteristics

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ABSTRACT

Cereal Chem. 70(6):676–684

Stickiness of spaghetti dried at high and low temperatures was studied using two cultivars of durum wheat that exhibited strong or weak gluten properties. Some grain of each cultivar was artificially sprouted before milling. Portions of the semolina obtained from each were overground after milling to increase starch damage. Blends included all combinations of sprout-damaged and overground semolina, along with incorporations of spaghetti regrinds and monoglyceride. Selected biochemical components implicated with increased spaghetti stickiness were analyzed. The cooking quality, firmness, and stickiness of spaghetti produced from all blends were examined. High-temperature drying increased amylose content in cooked spaghetti and decreased the amount of amylose in the cooking waters. Sprouting caused an increase in total sugars in cooked spaghetti, whereas high-temperature drying caused a decrease. Concomitantly, it increased the total sugar in the cooking water. Sprouting caused higher cooking losses, decreased firmness, and lower spaghetti stickiness values. The incorporation of spaghetti regrinds increased stickiness; however, high-temperature drying decreased stickiness in similar samples. Monoglyceride alone had little effect on stickiness, but in combination with high-temperature drying, it decreased stickiness. Overgrinding increased amylose content of semolina, whereas semolina containing monoglyceride showed a reduced amylose content.

Firmness, elasticity, surface stickiness, cooking tolerance, water absorption, degree of swelling, and cooking water residue are, according to Manser (1981), the major factors used to properly assess spaghetti cooking quality. Of these factors, relatively few researchers have investigated surface stickiness of cooked spaghetti, primarily because it is difficult to quantify. As a method of measuring spaghetti stickiness, D'Egidio et al (1982) developed a total organic matter test to determine the amount of material that could be obtained by exhaustive rinsing of drained, cooked spaghetti. Although this method was very time-consuming and required a large sample size, it showed a close relationship to sensory and instrumental evaluation of cooked spaghetti stickiness.

Voisey et al (1978) developed the first instrumental method to measure spaghetti stickiness using an Instron Universal testing instrument. However, sensory evaluations and instrumental readings were not significantly correlated. Dexter et al (1983a) modified the Grain Research Laboratory compression tester and established a method for the instrument to assess surface stickiness of cooked spaghetti that was patterned after the method of Voisey (1978). The modifications reduced sample size, increased reproducibility, and broadened the range in stickiness values.

The apparent stickiness of a pasta sample (Dexter et al 1985) can be strongly affected by the amount of unabsorbed water associated with the drained, cooked product. These workers found a possible relationship between amylose content and stickiness. Amylose is defined as a linear polysaccharide composed of α-1,4 linked D-glucose units that are solubilized from swollen gelatinized starch granules. The leaching of amylose is intensified by damage to the starch granule.

Dexter et al (1983b) reported that stickiness was influenced by cultivar, wheat class, protein content, and raw material granulation. The raw material granulation factor suggested that perhaps starch damage played a role in stickiness.

Raw material granulation has been implicated in a number of cooking quality faults, including loss of solids into the cooking water during cooking, decreased firmness, and a possible increase in stickiness. Several studies (Seyam et al 1974, Matsuo and Dexter 1980, Dexter et al 1983b, Mousa et al 1983) have confirmed the first two cooking faults, but no conclusive evidence has been written implicating starch damage in stickiness of cooked pasta.

The purpose of this research was to investigate possible causes of spaghetti stickiness. The approach to the problem was threefold. First, certain biochemical components implicated with increased spaghetti stickiness were analyzed and monitored. Second, starch damage levels were manipulated in semolina through overgrinding, and the resultant effects on cooking quality parameters were studied. Finally, an adaptation of a method to test spaghetti stickiness was implemented, and the subsequent correlation of stickiness to other cooking-quality parameters was examined.

MATERIALS AND METHODS

Samples

The durum wheat cultivars used in this study (Vic and Ward) were field-plot samples grown at Minot, ND, and were chosen for their respective strong and weak gluten characteristics.

Before milling, a portion of grain of each cultivar was artificially sprouted. The grain (4,000 g) was covered with distilled water

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and allowed to soak at room temperature (25° C) for 24 hr, then drained on large screen trays and placed in a laboratory pasta drier. The initial temperature and relative humidity of the drier (25° C and 50%, respectively) were raised steadily over 1 hr to 40° C and 99.5% rh. These parameters were held constant during the germination period (24 hr). The temperature and relative humidity were then lowered over a 2-hr period to the original conditions, and the grain was dried to ~13% moisture. After the rootlets were removed, the grain was tempered for milling.

The unsprouted and sprouted wheat samples were tempered using a three-step tempering process that raised the moisture to 16.0% over a 48-hr period. Samples were then milled on a Buhler experimental mill. After milling, a portion of semolina obtained from the unsprouted and sprouted wheat of both cultivars was overground to increase starch damage. Overgrinding was performed on an Allis-Chalmers single-stand roller mill according to the method of Okada et al (1986).

Preparation of Regrinds

Spaghetti produced from unsprouted Ward and Vic semolina and dried at both high temperature (HT) and low temperature (LT) was used to produce regrinds. Spaghetti was ground using a Thomas-Wiley laboratory mill to pass a 0.5-mm screen. This produced a particle size similar to that of semolina.

Preparation of Sprouted Semolina Samples

Semolina from the milled, sprouted durum was blended with unsprouted semolina counterparts using the enzyme blending number method of Perten (1964). A calculated amount of the sprouted semolina was blended with a calculated amount of the unsprouted semolina to arrive at a predetermined falling number value. For this study a falling number value between 150 and 200 was desired. After blending, the final falling number values were 196 and 167 for Vic and Ward, respectively.

Preparation of Semolina Blends

Blends were made using a 2^6 fractional factorial random block design (Cochran and Cox 1950). Semolina from either Vic (strong gluten) or Ward (weak gluten) was incorporated with or without sprout damage, overgrinding, the addition of spaghetti regrinds, and the addition of a concentrated glycerol monostearate (Myvaplex 600, 1.75%, Eastman Chemical Products, Kingsport, TN).

The experimental design also included either an LT or HT drying cycle for the spaghetti produced from the various blends with all possible combinations, resulting in 32 units (Table I).

Starch Damage

The amount of damaged starch in the semolina blends was determined using the methods of Farrand (1964) and Williams and Fegol (1969).

Amylose Content

Amylose content of the semolina blends, and of the uncooked and freeze-dried cooked spaghetti, was determined according to the method of Williams et al (1970) with modifications. The samples were milled to pass through a 60-mesh screen on a Wiley Jr. laboratory mill (Arthur H. Thomas Co., Philadelphia, PA) before use. Twenty milligrams of each sample were weighed directly into beakers (50 ml) and dispersed, with stirring, in 10 ml of 0.5*N* potassium hydroxide for 1 hr. Samples were then diluted (Williams et al 1970), and absorbance of the blue color was measured at 625 nm after 30 min.

Total Sugar Content

Total sugars in the ground spaghetti were determined using the extraction procedure of Ponte et al (1969), with one modification. The sample was extracted twice instead of once, using the ternary solvent system. The phenol-sulfuric acid colorimetric method of Dubois et al (1956) was used to determine the

TABLE I
Blending Schematic for Semolina Samples[a]

Semolina Blend	Gluten Strength	Overground	Sprout Damage	Spaghetti Regrinds	Monoglyceride	Spaghetti Drying Cycle
1	S	−	−	+	−	L
2	S	+	−	+	+	L
3	S	+	+	+	−	L
4	S	−	+	+	+	L
5	S	−	+	−	−	L
6	S	+	+	−	+	L
7	S	+	−	−	−	L
8	S	−	−	−	+	L
9	S	+	−	−	+	H
10	S	+	+	+	+	H
11	S	+	+	−	−	H
12	S	−	+	−	+	H
13	S	−	+	+	−	H
14	S	+	−	+	−	H
15	S	−	−	−	−	H
16	S	−	−	+	+	H
17	W	−	−	+	+	L
18	W	+	−	+	−	L
19	W	+	−	−	+	L
20	W	−	−	−	−	L
21	W	+	+	−	−	L
22	W	+	+	+	+	L
23	W	−	+	+	−	L
24	W	−	+	−	+	L
25	W	−	−	−	+	H
26	W	+	−	−	−	H
27	W	−	−	+	−	H
28	W	+	−	+	+	H
29	W	−	+	+	+	H
30	W	−	+	−	−	H
31	W	+	+	+	−	H
32	W	+	+	−	+	H

[a] S = strong gluten cultivar (Vic); W = weak gluten cultivar (Ward); + = component or process included in blend; − = component or process not included in blend; L = low temperature; H = high temperature.

amount of sugar in all the extracts. Sucrose was used to establish a standard curve. The results were expressed as percentage of sucrose.

Pasta Processing and Drying

Each semolina blend (1,000 g) was mixed and extruded separately. Enough distilled water (40°C) was added to obtain an absorption of 31.5%. The sample was mixed in a Hobart mixer (Hobart Mfg. Co., Troy, OH) at high speed until uniformly amalgamated (~3 min). It was then transferred to a DeMaco semicommercial-scale vacuum pasta extruder. The dough was pressed through an 84-strand, 0.157-cm diameter Teflon spaghetti die according to the procedure of Walsh et al (1971).

Two drying cycles were used. The conventional LT cycle and the Buhler two-stage HT drying cycle. Briefly, the differences in the two drying cycles were: 1) total drying time, 18 hr for LT and 12 hr for HT; 2) temperature, 40 to 25°C for LT and 30 to 56 to 72°C and back to 30°C for HT; and 3) relative humidity, 95 to 50% for LT and 77 to 83 to 50% for HT.

Cooked Spaghetti Analysis

A modification of the procedure of Dick et al (1974) was used for cooking. Spaghetti (10 g) was broken into lengths of ~5 cm and was cooked in 300 ml of boiling distilled water. Spaghetti was cooked to its optimal cooking time (~10 min) and to 10 min past its optimal cooking time. Optimal cooking time was defined as the time required for the white core in the center of the strand to disappear. This was determined by removing a strand from the cooking water at 30-sec intervals and crushing it between two plexiglass plates. After cooking, the samples were rinsed with distilled water in a Buchner funnel and allowed to drain for 2 min. Each spaghetti sample was cooked to optimum and to 10 min past optimum three times on separate days. The third set of cooked, drained, unrinsed samples was freeze-dried immediately after cooking and analyzed later for amylose content. An aliquot of each of the cooking waters was frozen in small plastic bottles and analyzed later for total sugars. An additional aliquot of each of the cooking waters was analyzed for amylose content upon cooling after cooking.

Cooked Weight

Cooked weight was determined by weighing the drained and rinsed spaghetti and was reported in grams.

Cooking Loss

The combined cooking and rinse waters were collected in a tared beaker, placed into an air-oven at 110°C, and evaporated to dryness. The residue was weighed and reported as a percentage of the starting material.

Spaghetti Firmness

Spaghetti firmness was measured as described by Walsh and Gilles (1971) with an Instron Universal testing instrument. Two cooked spaghetti strands were sheared at a 90° angle with a specially designed plexiglass tooth. The force required to shear the spaghetti was measured in triplicate. The results were averaged and reported as g·cm. A higher value indicates a firmer product.

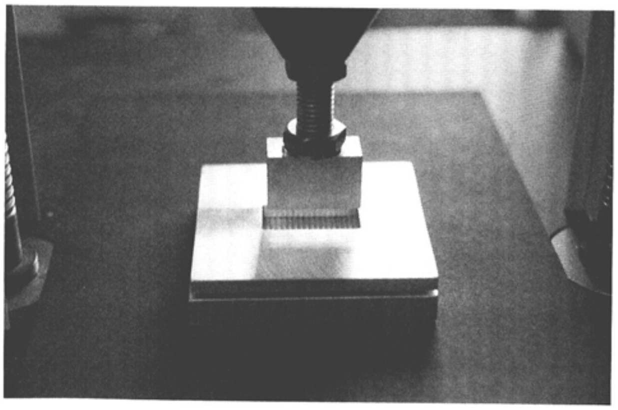

Fig. 1. Plunger assembly poised above spaghetti sample that is sandwiched between base plate and retainer plate.

Spaghetti Stickiness

Cooked spaghetti stickiness was determined using an Instron Universal testing instrument equipped with a universal cell and interfaced with a Zenith model 158 PC. The method was modeled after that of Dexter et al (1983a). Ten grams of spaghetti were broken into 5-cm long strands and cooked to optimum (~10 min) in 300 ml of buffered, hard water (pH 7.5). The formula used to prepare the water was described by Matsuo et al (1986). Because of constant fluctuations in city tap water, sufficient buffered hard water was prepared in advance to assure repeatability of the stickiness testing. The spaghetti was drained for 1 min over a U.S. 8 sieve and loaded onto three polished aluminum plates, similar to those used by Dexter et al (1983a), each measuring 100 × 100 × 6 mm. The strands of cooked spaghetti were laid side-by-side to cover an area about 5 cm wide. The plates were placed into square plastic containers and sealed with fitted covers during the interval between loading and testing (~6 min).

The most consistent results were obtained with a total time of 13 min between the end of cooking and beginning of testing. One minute before testing, an aluminum cover plate was placed over the spaghetti strands, and excess water was blotted with tissue. The cover plate, used as a retainer, was made of polished aluminum the same size as the bottom plate, but it had a rectangular opening in the center of the plate measuring 43 × 22 mm for plunger-to-sample access. The plunger, also rectangular in shape, had a polished aluminum contact surface of 40 × 19 mm. The plunger (Fig. 1) was fastened to the universal cell, which was attached to a 5-kg load transducer. The plunger was moved vertically with a computer software program designed to work with the Instron Universal testing instrument. Predetermined conditions were entered into the computer, and all movements up and down thereafter were controlled from the computer keyboard. The conditions used throughout the testing included a load range setting of 2, a crosshead speed of approximately 4 mm/min, and a maximum load value of 500 g. The force generated during the compression of the cooked spaghetti, and on lifting the plunger, was graphically plotted on the computer screen. Stickiness was defined as the maximum depression (negative value) recorded during lifting of the plunger. The negative value was calculated into N/m^2 using a factor of 5,200 N/m^2 for a compression force of 500 g.

Statistical Analysis

The data were analyzed statistically using the GLM procedure of the statistical analysis system (SAS 1986). The Duncan's multiple range test was applied to compare mean values.

RESULTS AND DISCUSSION

Semolina Starch Damage and Amylose Content

Starch damage mean values obtained by both the Farrand and the Williams and Fegol methods, as well as amylose content of the semolina blends, are shown in Table II. The regression equation used to calculate the Farrand equivalent units for the Williams and Fegol (1969) method was based on values obtained from hard red spring wheat flour and may not be applicable to durum semolina, which may explain the lower values obtained for semolina. The Duncan's test (Table III) showed that both starch damage methods were significantly influenced by cultivar, the addition of spaghetti regrinds, and overgrinding, all of which would be expected. With each of these variables, the influence of milling and the reaction to overgrinding were generally varietal characteristics, and the amount of starch damage imparted during these processes would have a definite influence on the semolina blends. Concomitantly, the addition of spaghetti regrinds also heightened the probability of increased starch damage.

Sprouting and monoglyceride showed no effect on starch damage values for either method. Monoglyceride exerted a highly significant effect on amylose content in the various semolina blends. For both cultivars, amylose values obtained for semolina blends containing overground semolina, such as blends 3, 7, 11, and 26, were higher than those of blends that contained both overground semolina and monoglyceride (blends 6, 9, 10, and 19) (Table II). The addition of monoglyceride to semolina appeared to inhibit the loss of soluble carbohydrates, which may have a significant effect on stickiness of pasta. Matsuo et al (1986) reported that using commercial monoglycerides decreased stickiness and improved tolerance to overcooking.

Analysis of Uncooked Spaghetti Starch Damage, Amylose Content, and Total Sugars

Starch damage values of the uncooked spaghetti (measured according to the Farrand method and the Williams and Fegol method), amylose content, and total sugars are shown in Table IV. Starch damage values were higher than those obtained for semolina starch damage (Table II). These results agreed with those reported by Lintas and D'Appolonia (1973), who attributed the increase in starch damage to mechanical damage occurring during mixing and extrusion and to amylolytic enzyme activity during processing, particularly during the drying cycle. In addition, the increase in starch damage may also reflect, to some degree, the grinding process used to grind the dry spaghetti for starch damage analysis.

The Duncan's test (Table V) showed that cultivar had a highly significant effect on starch damage, which agrees with semolina starch damage. Analysis of least significant means showed higher values from both methods for the spaghetti processed from blends derived from Vic semolina. Unlike the semolina starch damage, however, the addition of monoglyceride exerted a highly significant effect on spaghetti starch damage. When monoglyceride was a constituent in the same blend, lower spaghetti starch damage was realized for both methods of starch damage analysis, but especially for the Farrand method. The combined effect of spaghetti drying temperature and monoglyceride also showed a significant difference for both methods of starch damage analysis. The lowest starch damage values were obtained from spaghetti samples containing monoglyceride and dried using the HT drying cycle. Spaghetti samples containing no monoglyceride and dried

TABLE III
Semolina Starch Damage and Amylose Content

	Starch Damage[a]		Amylose Content (%)
	I (FU)	II (FEU)	
Variety			
Vic	25.7 a[b]	13.0 a	5.0 a
Ward	29.1 b	17.0 b	5.2 a
Sprouting			
With	27.5 a	14.9 a	5.1 a
Without	27.3 a	15.1 a	5.4 a
Regrinds			
With	29.5 a	21.7 a	5.3 a
Without	25.3 b	8.2 b	4.9 a
Overgrinding			
With	35.1 a	16.9 a	5.1 a
Without	19.7 b	13.0 a	5.0 a
Monoglyceride			
With	26.9 a	14.6 a	4.4 a
Without	27.9 a	15.4 a	5.8 b

[a] I = Method of Farrand (1964), FU = Farrand units. II = Method of Williams and Fegol (1969), FEU = Farrand equivalent units.

[b] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.

TABLE II
Starch Damage and Amylose Content of Semolina Blends

Semolina Blend	Starch Damage		Amylose Content (%)
	Method I (FU)[a]	Method II (FEU)[b]	
1	19.2	14.9	6.0
2	35.4	20.8	4.5
3	37.2	24.6	6.1
4	19.4	15.5	4.4
5	15.2	7.6	5.9
6	32.7	9.8	4.1
7	33.0	10.0	6.2
8	13.7	5.8	4.0
9	31.8	9.7	4.8
10	33.8	19.7	4.9
11	33.9	12.2	6.1
12	14.9	6.7	3.1
13	15.8	6.9	5.7
14	40.2	22.4	5.1
15	16.7	6.0	5.5
16	18.8	16.1	3.5
17	24.5	23.6	5.1
18	40.2	27.3	5.1
19	35.4	9.2	3.7
20	15.3	7.4	4.8
21	33.6	11.9	4.7
22	35.4	23.9	4.0
23	27.3	24.0	6.2
24	21.5	7.9	5.0
25	15.3	5.4	5.0
26	36.3	12.7	6.1
27	22.4	29.3	6.3
28	38.4	24.9	5.2
29	28.6	25.0	5.4
30	23.6	8.0	6.1
31	36.0	29.3	7.0
32	31.1	9.4	3.3

[a] Method of Farrand (1964). FU = Farrand units.

[b] Method of Williams and Fegol (1969). FEU = Farrand equivalent units.

TABLE IV
Chemical Analysis of Uncooked Spaghetti

Spaghetti Sample	Starch Damage[a]		Amylose (%)	Total Sugar (%)
	I (FU)	II (FEU)		
1	77.2	22.3	6.4	5.4
2	73.9	17.7	4.2	4.2
3	85.3	28.2	6.0	5.5
4	70.3	21.7	3.9	4.6
5	76.3	24.2	5.4	6.0
6	75.0	22.0	4.4	4.5
7	77.4	20.4	5.8	4.3
8	63.7	14.4	3.7	3.8
9	56.7	13.6	4.4	9.0
10	58.6	17.6	3.5	11.5
11	83.6	23.6	6.8	12.0
12	46.8	15.3	4.2	11.1
13	67.2	21.4	6.9	11.5
14	80.9	26.4	6.5	9.7
15	73.8	23.7	7.9	10.3
16	51.6	16.3	5.0	9.3
17	62.6	15.6	4.2	4.1
18	80.4	20.1	5.7	3.1
19	71.7	13.2	4.2	3.8
20	72.0	17.2	5.4	4.3
21	75.4	21.4	4.4	5.8
22	65.4	18.0	2.6	6.3
23	82.9	26.4	5.0	5.4
24	64.2	17.2	2.5	4.6
25	48.8	11.7	3.9	9.3
26	72.6	16.5	5.7	9.2
27	73.2	26.3	6.2	10.2
28	63.6	14.4	4.0	9.4
29	54.7	14.8	3.1	11.2
30	65.2	19.1	3.8	12.1
31	80.0	28.0	5.3	13.1
32	53.7	13.3	2.7	13.6

[a] I = Method of Farrand (1964); FU = Farrand units. II = Method of Williams and Fegol (1969); FEU = Farrand equivalent units.

at conventional temperature (LT) exhibited the highest spaghetti starch damage values. These results indicated that the amount of maltose liberated by amylolytic enzyme activity during spaghetti processing, and the simultaneous conversion of maltose into glucose as suggested by Lintas and D'Appolonia (1973) and later by Kruger and Matsuo (1982), was greatly reduced due to amylose-monoglyceride binding.

TABLE V
Uncooked Spaghetti Starch Damage, Amylose Content and Total Sugars

	Starch Damage[a]		Amylose Content (%)	Total Sugars (%)
	I (FU)	II (FEU)		
Variety				
Vic	69.9 a[b]	20.6 a	5.3 a	7.7 a
Ward	67.9 b	18.3 b	4.2 b	7.8 a
Sprouting				
With	69.0 a	20.7 a	4.4 a	8.7 a
Without	68.7 a	18.1 b	5.0 a	6.8 b
Regrinds				
With	70.5 a	20.9 a	4.9 a	7.8 a
Without	67.3 a	17.9 b	4.5 a	7.7 a
Overgrinding				
With	72.1 a	19.7 a	4.8 a	7.8 a
Without	65.6 b	19.2 a	4.7 a	7.7 a
Monoglyceride				
With	61.3 a	16.0 a	3.7 a	7.5 a
Without	76.4 b	22.8 b	5.8 b	8.0 a
Drying Temperature				
High	64.4 a	18.8 a	4.8 a	10.8 a
Low	73.3 b	20.0 a	4.6 a	4.7 b

[a] I = Method of Farrand (1964); FU = Farrand Units. II = Method of Williams and Fegol (1969); FEU = Farrand equivalent units.

[b] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.

The spaghetti amylose content, like that of semolina, showed highly significant associations with cultivar and monoglyceride. Spaghetti processed from semolina containing monoglyceride showed lower values of amylose, indicating the effectiveness of the amylose-monoglyceride complex formed during mixing and extrusion. Higher amylose content was observed for spaghetti processed from blends containing Vic semolina, which explains the statistically significant effect shown between cultivar and amylose content. Likewise, higher values were obtained for spaghetti made from blends of sound wheat semolina, which was expected. An increase in amylolytic enzymes in the sprouted samples would reduce amylose during the mixing and extruding phases of processing, resulting in the release of free maltose. Amylose content was not affected by the addition of regrinds, drying temperature, or overgrinding.

The amount of total sugar in the various spaghetti samples is shown in Table IV. Total sugar obtained for samples derived from sprouted durum showed exceptionally high values for both cultivars (samples 10, 11, 12, and 13 for Vic and 29, 30, 31, and 32 for Ward). These higher values may be caused by the artificial sprouting of the durum used in this study. Ibrahim (1982) reported values around 6.0% for spaghetti derived from field-sprouted durum. This would be an expected result because of the increase in reducing sugars produced by amylolytic enzyme activity during germination. Ibrahim (1982) reported a two- to threefold increase in spaghetti total sugar over that of semolina total sugar. He also reported that, by increasing spaghetti drying temperature from 40 to 80°C, a decrease in total sugar content was obtained. In direct contrast, the current study showed a dramatic increase in total sugar when HT drying at 72°C was employed. The difference between the former study and the current study may be the difference in HT cycles used or differences in the efficiency of the laboratory dryers used. The increase in total sugar was observed no matter what cultivar or treatment was involved,

TABLE VI
Spaghetti Cooking Quality Data

Cooked Spaghetti Sample	Cooked Weight		Cooking Loss		Firmness		Stickiness
	Optimum (g)	Optimum + 10 Min (g)	Optimum (%)	Optimum + 10 Min (%)	Optimum (g·cm)	Optimum + 10 Min (g·cm)	Optimum (N/m²)
1	29.0	38.7	6.4	8.9	6.3	4.5	754
2	28.4	35.2	6.7	9.1	5.9	5.0	541
3	28.4	36.5	7.0	9.8	6.3	4.7	557
4	27.8	34.6	7.0	9.4	6.4	5.0	520
5	28.0	37.0	6.7	9.1	6.3	4.5	551
6	27.3	35.1	6.9	9.1	5.8	5.0	427
7	28.1	36.5	6.6	9.7	6.4	4.7	515
8	28.2	35.0	6.6	8.7	5.9	5.1	442
9	26.5	35.3	5.2	7.2	6.1	4.7	447
10	27.3	35.8	5.8	8.1	5.4	4.3	437
11	29.3	37.7	5.8	8.2	6.2	4.1	375
12	26.9	35.7	5.4	8.0	5.9	4.4	406
13	28.7	37.8	6.0	8.2	5.9	4.1	390
14	29.3	37.7	5.7	7.9	6.4	4.3	375
15	29.0	39.1	5.4	8.1	6.1	4.0	525
16	27.0	36.0	5.6	7.6	6.0	4.3	416
17	27.8	36.5	6.4	8.7	5.3	4.4	645
18	28.8	37.7	6.5	9.0	5.3	4.1	531
19	28.0	36.2	6.4	9.4	4.7	4.0	754
20	30.1	39.0	6.2	8.7	5.4	4.2	600
21	29.0	38.8	7.2	9.6	4.8	3.7	354
22	28.1	37.0	7.1	10.0	4.7	3.8	437
23	28.5	36.7	6.9	9.5	5.8	4.4	608
24	28.0	36.3	7.5	10.3	4.4	4.1	374
25	27.4	36.0	5.2	7.3	4.9	3.8	312
26	29.2	38.1	5.4	7.7	5.0	3.5	463
27	29.6	39.4	5.3	7.6	5.0	3.5	510
28	28.1	37.1	5.4	7.6	4.6	3.6	474
29	28.4	38.2	5.8	8.2	4.2	3.5	390
30	28.7	38.8	5.8	8.2	5.0	3.0	473
31	29.3	38.8	6.0	9.0	5.2	3.2	577
32	28.9	38.0	6.4	9.0	4.2	3.1	396

except for the addition of monoglyceride. According to the Duncan's test (Table V), analysis of least significant means revealed that total sugar values obtained for spaghetti samples containing monoglyceride, regardless of cultivar, were lower than those of samples without monoglyceride. These results were obtained for both LT and HT dried spaghetti. Monoglyceride also slightly reduced total sugar content of spaghetti samples derived from the sprouted wheat.

Analysis of Cooked Spaghetti

Cooking quality encompasses many physical and chemical tests, some of which are cooked weight, cooking loss, firmness, and stickiness. However, when addressing cooking quality, it is difficult to separate each individual factor because the biochemical changes taking place during cooking ultimately affect other factors or a combination of several factors.

The cooking quality data for the 32 spaghetti samples are shown in Table VI. Cooked weight and cooking loss both increased as length of cooking time increased, whereas firmness decreased. There appeared to be no differences between the two cultivars. However, after being cooked 10 min past optimum, those samples derived from the weaker gluten cultivar (Ward) showed slightly higher cooked weight than that of the samples derived from Vic, indicating a slightly softer product for the Ward spaghetti samples. For samples with sprouting, cooked weight at the longer cooking time was less than that for the samples without sprouting. Kruger and Matsuo (1982) found that high amylolytic activity increased cooking water residue in both laboratory-germinated and field-sprouted samples. They also reported a slightly softer cooked spaghetti. In contrast, Dick et al (1974) reported that cooked weight, cooking loss, and spaghetti firmness were not significantly affected by field sprouting. Firmness (Table VII) showed significant differences between the two cultivars. The spaghetti samples processed from the strong gluten cultivar (Vic) were definitely more firm than the samples derived from Ward. Matsuo and Irvine (1970) stated that the type of gluten was an important factor in determining tenderness or firmness in cooked spaghetti. They showed a relationship between a softer cooked product and weak gluten semolina. Conversely, strong gluten semolina was associated with a firmer cooked product. Grzybowski and Donnelly (1979) also reported that protein content and gluten strength were correlated with cooking loss and cooked firmness, but they found no relationship between those factors and cooked weight. Contrary to these reports, the statistics of Matsuo et al (1982) showed that there was no significant correlation between tenderness index and semolina protein; the tenderness index appeared to be influenced more by starch gel properties and level of α-amylase in the semolina. In agreement with Matsuo's findings, the current study showed that sprouting had a significant influence on cooking loss at both cooking times; samples derived from the weaker gluten cultivar (Ward) sustained higher losses than samples made from the strong gluten cultivar (Vic).

Several investigators (Dexter et al 1981, Ibrahim 1982, Wyland and D'Appolonia 1982) have shown an improving effect on cooking quality factors with increased spaghetti drying temperature. The current study basically agreed with these investigations for cooking loss and cooked weight, but not for firmness. In contrast to reports by other investigators, firmness values for the current study (Table VII) decreased slightly with HT drying for both cultivars, whether unsprouted or sprouted. These differences reflect the influence of HT drying on only two cultivars. Because the difference was statistically insignificant, it should not be stated that HT drying had an adverse effect on firmness. It was possible that interactions of main-effect variables played a role in the differences observed. One of these interactions could be the effect of monoglyceride, which significantly influenced cooked weight as well as firmness (Table VII). The addition of monoglyceride caused cooked weight to decrease for both cultivars at both cooking times, whereas cooking loss remained the same. As cooking progressed, the lipid-starch-protein binding effect of the monoglyceride was more apparent, showing less disintegration of the starch and protein components.

The other main effect variables that could have caused a reduction in firmness were the addition of regrinds or fine-particle-size semolina or flour from overgrinding in certain blends. Dexter and Matsuo (1978) stated that spaghetti cooking quality did not change detectably as semolina extraction rate increased; they also found that cooking quality of the coarse semolina did not differ significantly from semolina with a smaller average particle size. This work agreed with that of Seyam et al (1974); however, these workers showed an increase in cooking loss with the finer grind and significant differences in firmness. Donnelly (1980) showed increased cooking losses in blends containing regrinds and decreased firmness as the percentage of regrinds increased. He found no effect on cooked weight until cooking time went beyond 15 min. Analysis of least significant means (Table VII) showed basically no influence on cooked weight or cooking loss by the addition of regrinds or overgrinding.

TABLE VII
Spaghetti Cooking Quality Parameters[a]

	Cooked Weight		Cooking Loss		Firmness	
	Optimum (g)	Optimum + 10 Min (g)	Optimum (g)	Optimum + 10 Min (g)	Optimum (g·cm)	Optimum + 10 Min (g·cm)
Variety						
Vic	28.1 a	36.2 a	0.62 a	0.86 a	6.1 a	4.5 a
Ward	28.6 b	37.7 b	0.62 a	0.87 a	4.9 b	3.7 b
Sprouting						
With	28.3 a	36.8 a	0.65 a	0.90 a	5.4 a	4.0 a
Without	28.4 a	37.1 a	0.59 b	0.83 b	5.6 a	4.2 a
Regrinds						
With	28.4 a	36.8 a	0.62 a	0.87 a	5.5 a	4.1 a
Without	28.3 a	37.0 a	0.62 a	0.86 a	5.4 a	4.1 a
Overgrinding						
With	28.4 a	37.0 a	0.63 a	0.88 a	5.4 a	4.1 a
Without	28.3 a	36.9 a	0.61 a	0.85 a	5.5 a	4.2 a
Monoglyceride						
With	27.8 a	35.8 a	0.62 a	0.86 a	5.3 a	4.2 a
Without	28.9 b	38.1 b	0.62 a	0.87 a	5.7 b	4.0 a
Drying Temperature						
High	28.3 a	37.2 a	0.56 a	0.80 a	5.3 a	3.8 a
Low	28.3 a	36.7 a	0.68 b	0.93 b	5.6 a	4.4 b

[a] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.

Stickiness of Cooked Spaghetti

Of all the major cooking quality factors, surface stickiness or gumminess of cooked spaghetti has received the least attention by researchers. Dexter et al (1983b) reported that stickiness of spaghetti was influenced by cultivar, wheat class, raw material granulation, and protein content but not by sprout damage.

Stickiness values of cooked spaghetti samples are shown in Table VI. Values ranged from 754 to 312 N/m^2, indicating a fairly wide range of stickiness for the samples examined. Higher values indicate greater stickiness. Statistical analysis (Table VIII) showed that stickiness was not affected by cultivar. These results were unexpected because the two cultivars used in this study had similar protein content but different gluten strength characteristics. These results suggest that strand disintegration during cooking is not related as much to protein content as it is to protein quality. Therefore, the presence or absence of certain gluten components may play a significant role in spaghetti stickiness.

Duncan's multiple range test (Table VIII) indicated a significant difference between samples containing sprout-damaged semolina and those without. In contrast to work reported by Dexter et al (1990), the present study showed that with sprout damage there was a decrease in stickiness. Perhaps the sprouted samples, which showed a higher cooking loss and higher total sugar in the cooking water, lost the majority of the soluble carbohydrates into the cooking water, leaving very little on the surface of the drained spaghetti. Statistical analysis revealed that stickiness was significantly correlated with cooking loss ($r = 0.71$).

In general, HT drying reduced stickiness. Therefore, the higher stickiness of the unsprouted samples showed an improving effect with HT drying, whereas the sprouted samples, which already showed less stickiness, did not show a further decrease in stickiness.

Although the addition of regrinds did not appear to influence spaghetti stickiness, according to the Duncan's test (Table VIII), samples derived from Vic blends showed a slightly stickier texture than did samples derived from Ward. Spaghetti drying temperature also exerted an effect on samples containing regrinds. Spaghetti dried using the conventional LT drying cycle had higher stickiness with regrinds present in the sample. HT drying showed basically the same differences with or without regrinds, although the lower values obtained using HT indicated an improving effect of HT drying.

A slight influence was observed between cultivar and overgrinding in relation to stickiness. Although differences were small, Ward overground samples were more sticky than Vic overground samples. The Vic samples, without overgrinding, were much more sticky than Ward samples without overgrinding. These observations may explain the significant interaction of cultivar and overgrinding on firmness of cooked spaghetti. In general, as particle size decreases, as in the case of overground semolina, water absorption increases, and consequently, firmness decreases. The spaghetti processed from overground Ward blends had lower firmness values than those of Vic. It also showed higher stickiness than spaghetti processed from overground Vic. This may be a result of the weaker gluten for Ward and the starch damage imparted by excessive overgrinding. On the other hand, the spaghetti processed from Vic blends without overgrinding were much stickier than the Ward blends without overgrinding, which may reflect the higher amount of finer particle-size material of the original Vic semolina.

TABLE VIII
Spaghetti Stickiness

	Stickiness (N/m^2)
Cultivar	
Vic	450 a[a]
Ward	493 a
Sprouting	
With	454 a
Without	518 b
Regrinds	
With	509 a
Without	463 a
Overgrinding	
With	479 a
Without	495 a
Monoglyceride	
With	463 a
Without	509 a
Drying Temperature	
High	435 a
Low	537 b

[a] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.

Amylose Content of Cooked Spaghetti and Spaghetti Cooking Water

Amylose content of the cooked, freeze-dried spaghetti and the corresponding cooking waters, at both cooking times, are shown in Table IX. Amylose content of the cooked spaghetti from Vic blends was slightly higher at both cooking times. This might partially explain why Vic was more firm than Ward; higher amylose is associated with higher firmness values.

Spaghetti derived from unsprouted wheat contained more amylose than spaghetti derived from sprouted wheat. This suggests that more amylose was leached into the cooking water from the sprouted samples during cooking, particularly at the longer cooking time. This is reflected in the higher amylose values of the cooking water for the sprouted samples.

Drying temperature had a highly significant effect on amylose content. Cooked HT-dried spaghetti retained higher amounts of amylose than did LT-dried spaghetti. However, the iodine method for estimating amylose is limited because of interference created by some lipid components. The possibility of greater amylose-lipid complexing with HT drying might explain the higher amount of amylose in these samples, thus accounting for some of the reduction in cooking loss and stickiness. Surfactants, such as the

TABLE IX
Amylose Content of Cooked Spaghetti and Spaghetti Cooking Water

	Cooked Spaghetti		Cooking Water	
Sample	Optimum (%)	Optimum + 10 Min (%)	Optimum (%)	Optimum + 10 Min (%)
1	3.6	2.1	2.4	5.6
2	1.5	1.1	0.9	4.2
3	3.4	2.2	2.5	4.8
4	1.2	1.0	1.5	4.4
5	3.3	1.1	2.6	6.7
6	1.4	0.8	1.5	5.6
7	3.4	2.4	2.5	5.2
8	1.8	0.8	1.6	3.3
9	1.8	1.4	0.0	3.7
10	2.5	1.4	0.0	3.1
11	4.3	3.2	2.6	3.1
12	3.0	1.9	0.9	6.6
13	3.4	1.9	2.4	5.6
14	3.3	3.0	3.2	3.8
15	3.3	2.9	3.1	3.9
16	3.6	2.2	1.5	6.0
17	1.2	1.1	1.2	4.2
18	3.3	2.4	1.9	5.2
19	1.2	0.9	0.0	3.0
20	2.5	1.3	2.2	5.2
21	1.5	1.2	2.3	6.1
22	1.4	0.7	0.6	4.1
23	2.4	1.6	2.4	5.7
24	1.0	0.3	1.5	5.5
25	2.3	1.5	0.0	5.0
26	3.2	2.7	1.3	6.4
27	3.3	3.0	2.7	6.6
28	1.8	1.4	0.0	5.8
29	1.8	1.4	0.0	6.7
30	2.8	1.8	2.2	3.9
31	3.2	1.9	2.2	3.9
32	2.2	1.2	0.0	2.8

TABLE X

Amylose Content and Total Sugars of Cooked Spaghetti and Spaghetti Cooking Water[a]

	Cooked Spaghetti				Cooking Water			
	Amylose Content		Total Sugars		Amylose Content		Total Sugars	
	Optimum (%)	Optimum + 10 Min (%)	Optimum (%)	Optimum + 10 Min (%)	Optimum (%)	Optimum + 10 Min (%)	Optimum (%)	Optimum + 10 Min (%)
Variety								
Vic	2.8 a	1.8 a	3.0 a	2.4 a	1.8 a	4.7 a	1.2 a	1.3 a
Ward	2.3 b	1.6 a	3.4 b	2.4 a	1.3 b	5.0 a	1.1 a	1.3 a
Sprouting								
With	2.4 a	1.4 a	3.5 a	2.7 a	1.6 a	4.9 a	1.2 a	1.4 a
Without	2.7 a	1.9 b	2.8 b	2.1 b	1.5 a	4.8 a	1.1 a	1.2 b
Regrinds								
With	2.6 a	1.8 a	3.2 a	2.4 a	1.5 a	4.7 a	1.1 a	1.3 a
Without	2.5 a	1.5 a	3.1 a	2.4 a	1.6 a	5.0 a	1.2 a	1.3 a
Overgrinding								
With	2.6 a	1.6 a	3.2 a	2.4 a	1.3 a	4.4 a	1.2 a	1.3 a
Without	2.6 a	1.7 a	3.1 a	2.3 a	1.8 b	5.3 b	1.1 a	1.3 a
Monoglyceride								
With	1.9 a	1.4 a	3.1 a	2.3 a	0.7 a	4.6 a	1.1 a	1.3 a
Without	3.1 b	1.9 b	3.3 a	2.5 a	2.4 b	5.1 a	1.2 a	1.3 a
Drying Temperature								
High	3.0 a	2.0 a	3.0 a	2.1 a	1.4 a	4.8 a	1.3 a	1.5 a
Low	2.1 b	1.3 b	3.3 a	2.7 b	1.7 a	4.9 a	1.0 b	1.1 b

[a] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.

monoglyceride used in this study, form insoluble inclusion complexes with amylose and form the so-called V-amylose X-ray diffraction pattern (Zobel 1964). Table V shows that monoglyceride caused a decrease in amylose content in cooked spaghetti samples.

The addition of regrinds increased amylose content in the cooked spaghetti at both cooking times, but not enough to be statistically significant (Table X). Samples containing overground semolina showed no difference in amylose content. These results may be due to the decrease in particle size, which was a factor for both of these variables. Cooked spaghetti samples with regrinds, and those containing overground semolina, showed a similar decrease in amylose in the cooking waters. The decrease was significant for those sample containing overground semolina (Table X). This suggests that the amylose was bound. Perhaps the increased surface area created by the finer particle-size material increased the complexing of available amylose.

The Duncan's test (Table X) shows that more amylose was released into the cooking water at optimum cooking time for the samples derived from Vic. However, at the longer cooking time, more amylose was present in the cooking waters of Ward. Amylose in cooking water was significantly correlated with total sugar content ($r = 0.79$) and with spaghetti firmness ($r = 0.71$). This observation may explain, in part, why the Vic samples were slightly less sticky than the Ward samples.

Temperature of spaghetti drying showed a significant effect on amylose content where HT-dried samples yielded less amylose in the cooking water. These data agreed with the amylose data obtained for cooked spaghetti. The fact that the spaghetti contained higher amylose and the cooking water contained less amylose would indicate that HT drying inhibited the release of amylose during cooking. The effect of monoglyceride showed a significant improving effect by preventing amylose from leaching into the cooking water. As with the cooked spaghetti, amylose content for the cooking water showed a highly significant effect with overgrinding. This was caused by the significant decrease in cooking water amylose as a result of overgrinding, which was attributed to increased lipid-amylose complexing in these samples.

TABLE XI

Total Sugars of Cooked Spaghetti and Spaghetti Cooking Water

	Cooked Spaghetti		Cooking Water	
Sample	Optimum (%)	Optimum + 10 Min (%)	Optimum (%)	Optimum + 10 Min (%)
1	2.5	2.7	1.1	1.3
2	3.2	2.9	0.9	1.2
3	3.8	3.6	1.1	1.5
4	3.4	2.8	0.9	0.9
5	3.3	3.4	1.0	1.2
6	3.4	2.7	1.0	1.2
7	3.4	1.8	1.1	1.0
8	2.2	2.0	0.9	0.9
9	2.5	1.8	1.2	1.3
10	3.1	2.2	1.3	1.6
11	2.9	2.6	1.5	1.6
12	3.5	2.1	1.5	1.6
13	3.3	2.2	1.3	1.4
14	2.6	1.9	1.3	1.8
15	2.8	2.4	1.3	1.3
16	2.5	1.8	1.1	1.6
17	3.0	1.7	1.1	1.0
18	3.2	2.4	1.0	1.1
19	3.2	2.6	1.1	1.1
20	3.3	2.6	1.0	1.0
21	3.8	3.5	1.0	1.2
22	4.2	4.2	1.1	1.3
23	4.2	2.3	1.0	1.2
24	3.1	2.7	1.1	1.1
25	2.4	1.7	1.3	1.4
26	2.7	1.7	1.3	1.2
27	3.3	1.9	1.2	1.4
28	3.0	1.8	1.2	1.3
29	3.3	2.2	1.2	1.4
30	3.8	2.5	1.2	1.8
31	3.8	2.4	1.4	1.4
32	3.6	2.7	1.2	1.4

Total Sugars of Cooked Spaghetti and Spaghetti Cooking Water

The total sugar content of freeze-dried, cooked spaghetti and corresponding spaghetti cooking waters is shown in Table XI. Higher total sugar content in the samples cooked to optimum and a general reduction in total sugar content in the samples cooked past optimum was observed. This would be expected because total sugar in the cooking water increased as cooking time increased. These observations were consistent with the firmness values obtained for the two cooking times. In addition, total sugar content was significantly correlated with spaghetti firmness ($r = 0.75$). Spaghetti from laboratory-sprouted wheat had more sugar, so the effect of sprouting on total sugar content was not surprising.

Cooked spaghetti derived from germinated wheat released substantially more solids into the cooking water (Table X). The higher amount of solids in the cooking water of these samples resulted in a highly significant amount of total sugars. These observations were particularly true for spaghetti and cooking water collected from samples cooked 10 min past optimum.

As a result of HT drying (Table X), total sugars in the cooked spaghetti decreased and concomitantly increased in the cooking water.

CONCLUSIONS

Cooking quality of spaghetti processed from Vic and Ward durum semolina blends was judged at two cooking times: optimum and 10 min past optimum. Cooked weight and cooking loss increased as length of cooking time increased. Ward samples showed slightly higher cooked weights after the longer cooking time, indicating a softer product. Vic cooked spaghetti showed higher firmness values than those of Ward, which was attributed to the difference in gluten quality of the two cultivars. Sprouting caused higher cooking losses from the samples derived from Ward. In general, sprouting caused a decrease in firmness. HT drying caused a decrease in cooking loss, regardless of cultivar, sprout damage, or length of cooking time, but it did not appear to affect cooked spaghetti weight. All samples with added monoglyceride gave spaghetti with decreased cooked weights. Lower stickiness values were obtained for spaghetti processed from semolina made from sprouted wheat. This was attributed to the significant loss of soluble carbohydrates into the cooking water for these samples. HT drying reduced stickiness in all spaghetti samples made from unsprouted semolina, but it showed no effect on the samples made from sprouted semolina. Spaghetti processed from semolina that had regrinds incorporated was stickier than that without regrinds; however, HT drying decreased stickiness for those same samples containing regrinds. The addition of monoglyceride alone had a very small influence on stickiness, but, in combination with HT drying, a significant decrease was obtained. Spaghetti made from overground Ward blends, which had lower firmness values than those of Vic, showed more stickiness than spaghetti processed from overground Vic.

Amylose content of cooked spaghetti derived from Vic was slightly higher than that made from Ward. HT drying increased amylose content in cooked spaghetti and decreased the amount of amylose in the cooking water, thereby reducing stickiness. The addition of monoglyceride caused a decrease in amylose content in spaghetti, particularly when samples were cooked to optimum. The presence of regrinds and overground semolina increased amylose content in cooked spaghetti but decreased amylose in the cooking water. Total sugars in cooked spaghetti decreased as length of cooking time increased. Sprouting increased total sugar content in cooked spaghetti processed from sprouted semolina blends, whereas HT drying decreased the amount of total sugar in the cooked spaghetti; concomitantly, the total sugar in the cooking water was slightly increased.

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[Received December 29, 1992. Accepted June 14, 1993.]