The Spaghetti-Making Quality of Commercial Durum Wheat Samples with Variable α-Amylase Activity[1,2]

J. E. DEXTER, R. R. MATSUO, and J. E. KRUGER[3]

Cereal Chem. 67(5):405-412

ABSTRACT

Rail carlots of Canadian durum wheat unloading at terminal elevators during the 1985-1986 crop year were screened for falling number (FN) and protein content. Composites were prepared to give an FN range of 60 to 520 sec at constant wheat protein content. Semolina milling performance and gluten strength of the composites were not related to FN. Semolina FN was highly correlated to wheat FN despite an α-amylase activity retention range in semolina of 25-75% among samples. Liquefaction number of semolina was an excellent estimator of semolina α-amylase activity. The amylograph was ineffective in predicting α-amylase activity of semolina because the semolina dispersed poorly. However, when semolina was reduced into flour prior to performing the amylograph, amylograph mobility was highly correlated to semolina α-amylase activity. Whether dried at 39 or 70°C, the most highly sprouted sample (wheat falling number 60 sec) exhibited slight checking, which became more pronounced following three months' storage. None of the other samples, including 12 with wheat FN below 150 sec, exhibited checking. Cooked spaghetti stickiness, firmness, and resilience were not related to semolina α-amylase activity. A slight increase in cooking loss was apparent for samples with wheat FN below 150 sec, but the effect was too small to be of practical importance. There was no evidence that high α-amylase activity was detrimental to spaghetti storage stability as measured by strand strength and spaghetti cooking quality.

It is well documented that sprout damage is detrimental to wheat breadmaking quality, primarily due to elevated levels of α-amylase (Meredith and Pomeranz 1985). According to Buchanan and Nicholas (1980), a minimum wheat falling number of 200 sec is required to avoid the first indications of sprout damage problems in the bakery. These include reduced water absorption, which reduces bread yield per unit weight of flour (Tipples et al 1966), and sticky bread crumb, which can cause buildup on slicer blades leading to bread distortion and costly production shutdowns (Ibrahim and D'Appolonia 1979).

Sprout damage appears to be less of a quality problem in pasta manufacturing. It is generally conceded that sprout damage has little or no influence on pasta color (Combe et al 1988, Dick et al 1974, Matsuo et al 1982a, Matveef 1963). Other studies have concluded that sprout damage either has no influence on pasta cooking quality (Donnelly 1980, Dick et al 1974) or that the effects are subtle and only become apparent when sprout damage is severe (Combe et al 1988, Matsuo et al 1982a, Matveef 1963).

Despite the evidence to the contrary, the belief persists among pasta manufacturers that even moderate levels of sprout damage are detrimental to pasta cooking quality. Many North American and Japanese manufacturers demand a durum wheat falling number in excess of 300 sec for the manufacture of premium pasta products. Pasta processing problems attributed to sprout damage include uneven hydration and extrusion, strand stretching, and a high potential for checking and cracking upon storage (Donnelly 1980, Maier 1980).

The wet harvest of 1985 made sprout damage a major grading factor for Canada Western Amber Durum (CWAD) wheat. In response to numerous inquiries from pasta manufacturers about the implications of sprout damage on pasta quality, a durum wheat falling number survey of commercial rail carlots was conducted by the Grain Research Laboratory during the 1985-1986 crop year. The carlots were composited to yield a wide range of falling number at constant protein content to allow a detailed examination of the effects of sprout damage on spaghetti quality. The intent of this study was to extend previous reports by considering the effect of α-amylase activity on spaghetti stickiness and to determine whether drying procedure or storage time affected the strength and cooking quality of spaghetti prepared from semolina of variable α-amylase activity. The effectiveness of semolina amylograph peak viscosity and semolina falling number as predictors of semolina α-amylase activity is also examined.

[1]Contribution no. 651 of the Canadian Grain Commission, Grain Research Laboratory, Winnipeg, MB.

[2]Presented at the AACC 74th Annual Meeting, Washington, DC, October-November 1989.

[3]Canadian Grain Commission, Grain Research Laboratory, 1404-303 Main Street, Winnipeg, MB R3C 3G8.

MATERIALS AND METHODS

Wheat Samples

All samples used in the study were composed of Canadian Grain Commission Grain Inspection Division subsamples of CWAD wheat rail carlots unloading at Canadian terminal elevators during the 1985-1986 crop year. Each carlot sample was assessed for falling number by the method of Hagberg (1961) with modification in sample size as recommended by Tipples (1971) and for protein content by near-infrared reflectance spectroscopy using the automated digital analyzer (Williams et al 1978). Residues of carlot samples were composited on the basis of falling number and protein content to yield 103 samples with a narrow range of protein content and a wide range of falling number. Each composite sample was comprised of a minimum of 30 individual carlot samples.

Wheat Physical Properties

Each carlot composite sample was assigned a grade by a Canadian Grain Commission inspector, who also determined the percentage of sprouted kernels as defined in the Official Grain Grading Guide of the Canadian Grain Commission (Canadian Grain Commission 1988). Test weight was determined with a Schopper chondrometer using the 1-L container.

Milling

Thirty of the carlot composite samples were selected for milling in duplicate 3-kg lots. Samples were cleaned and tempered overnight to 16.5% moisture as described by Dexter and Tipples (1987). The mill room is controlled for temperature (21°C) and humidity (60% rh).

The Allis-Chalmers milling procedure described by Matsuo and Dexter (1980) was modified to increase semolina yield and to improve semolina quality (Fig. 1). Following the third and fourth break passes, a sifter unit similar to that described by Black et al (1980) was used rather than the Allis-Chalmers box sifter. The box sifter is still used following the fourth sizing pass. A fourth roll stand equipped with corrugated rolls was added to the mill to allow an additional break pass and two additional sizing passes. The efficiency of the laboratory purifier (Black 1966) was improved by installing a vibratory feed mechanism that maintains a uniform stream of stock going to the purifier and precisely regulates feed rate. Roll gaps are 1.3, 0.4, and 0.2 mm for the first three break passes, giving a release of stock through a 20-wire sieve (910-μm aperture) of about 4, 55, and 45%, respectively. The fourth break pass is a cleanup roll, and roll gap is set at minimum clearance (0.06 mm). Roll gaps are 0.4 mm for the first three sizing passes and 0.06 mm for the last two sizing passes. All break and sizing rolls are run dull to dull at a differential of 2:1, the settings that produce the best quality semolina under laboratory milling conditions (Dexter et al 1988).

Bran yield (wheat basis) is 12–14%, and a combined 7–9% of other feed is recovered from the purifiers and sifters. Flour (throughs of an 8XX sieve [193-μm aperture]) represents an additional 8–10% yield but is considered a by-product of semolina milling and is discarded. Semolina yield is expressed as a proportion of clean wheat on a constant moisture basis.

Wheat and Semolina Analytical Properties

The protein contents of the wheat carlot composite samples were determined in duplicate by the Kjeldahl procedure as modified by Williams (1973). Wheat gluten strength was assessed in duplicate by the sodium dodecyl sulfate (SDS)-sedimentation test of Axford et al (1978) as modified by Dexter et al (1980). Semolina ash content was determined by AACC method 08-01 (1983).

α-Amylase Tests

The falling numbers of wheat carlot composites were determined on 7-g samples from duplicate 300-g grinds (Tipples 1971) by the method of Hagberg (1961). The falling numbers of replicate semolina samples were each determined singly on 7-g samples.

Amylograms were obtained from 65 g of flour (14% moisture basis) in 450 ml of distilled water using the pin stirrer. Amylograph peak viscosity was determined as described in AACC method 22-10 (1983). Amylograms initially were performed singly on replicate semolina samples and then were repeated after semolina had been gradually reduced into flour (through an 8XX sieve) on an Allis-Chalmers roll stand equipped with smooth frosted rolls.

The method of Kruger and Tipples (1981) was used to determine α-amylase content. Residues from falling number grinds of wheat carlot composites were analyzed in duplicate. Replicate semolina and ground spaghetti samples were each analyzed singly.

Reducing Sugars

Reducing sugars were extracted from replicate semolina and ground spaghetti samples in duplicate as described by Matsuo et al (1982a), and reducing sugar contents of the extracts were determined by the method of Dygert et al (1965).

Spaghetti Processing

Replicate semolina samples were each processed singly using a Demaco semicommercial laboratory press (De Francisi Machine Corporation, Brooklyn, NY) under previously described extrusion conditions (Matsuo et al 1978). The extruded product was divided into two portions to permit drying by a 39°C drying program and a 70°C drying program. Details of rate of moisture loss in spaghetti and the temperature and relative humidity conditions throughout both cycles are described by Dexter et al (1981).

Spaghetti samples were wrapped in plastic and stored in a controlled environment room (21°C and 60% rh) prior to cooking quality and breaking strength evaluation. Samples were tested at one week and at three months after processing.

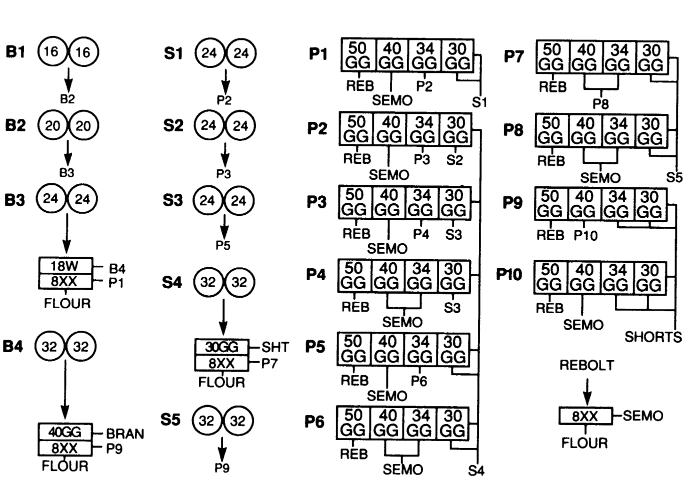

Fig. 1. Allis-Chalmers laboratory mill flow for durum wheat semolina incorporating modified Grain Research Laboratory sifter unit. **B** = break rolls, **S** = sizing rolls, **P** = purifier, **semo** = semolina, **reb** = stock to be rebolted.

Spaghetti Breaking Strength

The breaking strength of each spaghetti sample was determined by breaking 20 strands individually with the strain gauge assembly described by Matsuo (1978). The cross-sectional area of the spaghetti was computed from the mean diameter determined with a caliper, and breaking strength was computed as N/m^2.

Spaghetti Cooking Quality

Spaghetti cooking tests were measured in duplicate at optimum cooking time, determined for each sample by measuring the time required for the white core in the strands to disappear. Optimum cooking time was within a few sec of 12 min for all samples, regardless of storage time.

Cooking tests were performed on 10 g of spaghetti broken into 5 cm strands and cooked in 200 ml of boiling water. Cooking water of predetermined hardness was prepared as described by Dexter et al (1985a), eliminating the potential effect of variable cooking water hardness on cooked spaghetti stickiness and cooking loss (Dexter et al 1985b).

Cooking score, which combines instrumental measurements of firmness and elasticity, was obtained as described by Dexter et al (1988). Spaghetti stickiness was determined with a modified GRL compression tester (Dexter et al 1983a). Cooking loss, a measure of the loss of solids to the cooking water was determined as described by Dexter et al (1985a).

Statistical Analysis

Statistical analyses were performed with a personal computer using the SAS Stat Release 6.03 statistical program (SAS Institute, Cary, NC). The effects of sample (sprout level), spaghetti drying cycle, and spaghetti storage time were determined by completely randomized factorial analysis of variance. Where statistically significant ($P < 0.05$) effects were identified, the significance of differences between treatments was determined from least significant differences.

RESULTS AND DISCUSSION

Wheat Properties

Protein content and gluten strength are the primary quality factors influencing spaghetti cooking quality (Autran et al 1986, Matsuo et al 1982b). As seen in Table I, the narrow range of protein content and gluten strength (measured by SDS-sedimentation volume) of the durum wheat carlot composites allows the effects of sprout damage on spaghetti-making quality to be

TABLE I
Mean, Range, and Standard Deviation of Some Properties of 103 Durum Wheat Carlot Composites from the 1985–1986 Shipping Period[a]

Property	Mean	Range	Standard Deviation
Protein content, %	13.29	12.4–14.1	0.28
SDS sedimentation volume, ml	41.3	33.0–47.5	2.84
Sprouted kernels, %	1.8	0.0–12.0	2.2
Falling number, sec	294	60–520	114
Liquefaction number, 6000/(FN-50)	43.0	12.8–600	80.6
α-Amylase activity, units/g	59.2	3.2–676	80.6

[a] Protein content, falling number (FN), sodium dodecyl sulfate (SDS), and α-amylase activity expressed on 14% mb.

assessed in the absence of contributions from quantitative and qualitative differences in protein.

SDS-sedimentation volume was weakly correlated with α-amylase activity and the α-amylase related quality factors for the durum wheat carlot composites (Table II). The SDS-sedimentation test is a well-established predictor of durum wheat gluten strength (Dexter et al 1980, Dick and Quick 1983, Quick and Donnelly 1980), indicating that durum wheat gluten strength is not adversely affected by sprout damage.

The α-amylase related quality tests were all significantly correlated ($P < 0.01$) to α-amylase activity and to each other (Table II). However, as shown previously by Matsuo et al (1982a), the percentage of sprouted durum wheat kernels was not always a reliable indicator of α-amylase activity. For example, the 11 carlot composites that exhibited a falling number range from 300 to 310 sec contained from 0.0 to 3.6% sprouted kernels (results not shown).

As shown in previous reports (Corr and Spillane 1969; Kruger and Tipples 1979, 1981; Matsuo et al 1982a), the relationship between falling number and α-amylase activity was curvilinear (results not shown). Conversion of falling number values to liquefaction numbers (6000/[FN−50]) as suggested by Hlynka (1968) made the relationship to α-amylase activity more linear, as reflected by an improved correlation coefficient (Table II).

Detailed quality data for the 30 durum wheat carlot composites selected for spaghetti-making evaluation are presented in Table III. The samples were chosen to achieve a uniform distribution of sprout damage and α-amylase activity. The samples varied in grade from no. 2 to no. 4 CWAD. The major grading factors aside from sprout damage were weathering and mildew.

There was no significant correlation ($P > 0.05$) between semolina milling yield and α-amylase activity, falling number, or percentage of sprouted kernels. Test weight declined significantly ($P < 0.01$) as liquefaction number increased ($r = -0.69$) and α-amylase activity increased ($r = -0.58$).

Test weight was not correlated ($P > 0.05$) to semolina yield for these samples. Hook (1984) recently discussed in detail the limitations of test weight as a wheat milling quality predictor. For CWAD samples that have not undergone weathering, test weight is an excellent predictor of semolina milling potential

TABLE II
Correlation Coefficients of Test Results for 103 Durum Wheat Carlot Composites from the 1985–1986 Shipping Period

Property	PRO	SDS	SPR	FN	LN	AA
Protein content, %	1.00	−0.07	−0.24	0.29	0.07	−0.13
SDS[a] sedimentation volume, (SDS) ml		1.00	0.19	−0.24	0.13	0.23
Sprouted kernels (SPR), %			1.00	−0.72	0.63	0.78
Falling number (FN), sec				1.00	−0.49	−0.71
Liquefaction number (LN), 6000/(FN-50)					1.00	0.86
α-Amylase activity (AA), units/g						1.00

[a] Sodium dodecyl sulfate.

TABLE III
Wheat Properties of Carlot Composites Selected for Detailed Quality Testing

Sample	Test Weight (kg/hl)	Grade[a] (CWAD)	Protein Content[b] (% N × 5.7)	SDS[b,c] (ml)	Falling Number[b] (sec)	Sprouted Kernels (%)	Semolina Yield[d] (%)
1	79.6	2	13.5	44	460	0.0	66.1
2	79.6	2	13.1	44	450	0.0	66.4
3	79.4	3	13.1	40	375	0.0	64.0
4	79.6	2	13.3	41	375	0.0	64.6
5	79.0	3	13.0	43	360	0.0	64.3
6	79.1	2	13.3	40	340	0.0	64.9
7	79.4	2	13.3	44	355	0.0	64.7
8	79.6	3	13.0	38	310	3.1	64.2
9	79.6	3	13.6	39	300	3.5	64.0
10	79.0	3	13.5	42	255	1.0	65.2
11	78.5	3	13.3	41	270	4.7	65.1
12	78.9	3	13.1	38	235	4.0	64.8
13	78.8	3	13.2	46	210	0.4	65.3
14	79.1	2	13.2	47	230	0.2	65.8
15	79.2	3	13.3	43	200	0.2	65.0
16	78.5	3	13.0	44	180	1.0	64.5
17	79.3	3	13.1	44	190	1.2	63.6
18	76.6	3	14.1	40	140	2.0	64.4
19	77.0	4	12.9	41	150	1.4	65.4
20	78.9	2	13.0	44	140	3.0	64.2
21	77.1	4	13.6	40	125	3.8	64.9
22	79.1	2	13.4	42	120	0.5	65.5
23	78.7	3	13.5	44	125	3.0	65.5
24	78.1	3	13.4	40	120	5.0	65.9
25	78.3	4	13.2	38	110	4.3	64.4
26	78.2	4	13.4	44	145	4.9	65.4
27	77.7	4	13.2	42	105	5.8	65.5
28	79.3	3	13.4	44	110	7.9	65.7
29	77.2	3	13.2	42	60	8.0	64.2
30	77.0	4	13.2	44	60	12.0	64.1
Mean	78.6	...	13.3	42	220	2.7	64.9

[a] CWAD = Canada Western Amber Durum.
[b] Protein content, SDS, and falling number expressed on 14% mb.
[c] SDS = sodium dodecyl sulfate sedimentation volume.
[d] Semolina yield expressed as proportion of clean wheat on constant moisture basis.

because it is strongly related to kernel size and plumpness (Dexter et al 1987). The lower test weight of the most sprouted samples in the current study likely was due to increased porosity induced by moisture inbibition during weathering and would not be expected to influence milling yield (Dexter et al 1989).

Semolina ash content (results not shown) differed significantly ($P < 0.05$) among samples (range 0.61 to 0.71%), and when semolina yield was corrected to constant ash content (results not shown) as suggested by Dexter et al (1987), significant ($P < 0.05$) differences were found among samples (range 61.5 to 70.4%). However, neither semolina ash content nor semolina yield corrected to constant ash content was significantly ($P > 0.05$) correlated to percentage of sprouted kernels, falling number, or α-amylase activity.

Semolina color was not determined, because numerous previous reports (Combe et al 1988, Dick et al 1974, Matsuo et al 1982a, Matveef 1963) show that sprout damage does not affect color. There was a tendency towards increased semolina speckiness for the most sprouted samples (results not shown) as reported previously by Dick et al (1974). However, this is attributable to the mildew associated with the most sprouted samples rather than a direct cause of sprout damage (Dexter and Matsuo 1982).

α-Amylase Activity of Semolina and Spaghetti

The average retention of α-amylase activity in the semolina from the carlot composites was less than 50% of the activity in the wheat (Table IV). The proportion of wheat α-amylase retained following milling varies widely between wheat samples and within millstreams (Finney et al 1981, Henry et al 1987, Kruger 1981, Kruger and Tipples 1979, Matsuo et al 1982a). As a result, processing limitations associated with sprout damage can vary between wheat samples with comparable α-amylase activity. In the current study, α-amylase retention in semolina ranged from 27 to 73%. The variable retention of α-amylase between samples has been attributed to variable penetration of α-amylase into the wheat endosperm (Kruger and Reed 1988).

Spaghetti dried at 39°C retained about 75% of semolina α-amylase activity, in agreement with results of Matsuo et al (1982a). The retention of α-amylase following drying by a 70°C cycle similar to that widely used in modern pasta plants (Baroni 1988) was only about 50% of semolina α-amylase activity (Table IV). The lower temperature range for inactivation of α-amylase is near 70°C (Perten 1964) accounting for the lower α-amylase retention in the spaghetti dried by high temperature.

In North America, semolina falling number is frequently used as a primary quality specification by the manufacturers of high-quality pasta. In this study, semolina falling number (Table V) averaged about 100 sec more than wheat falling number (Table IV), although this difference will vary depending on milling extraction rate (Kruger 1981). Despite the variable retention of α-amylase activity in semolina among samples, semolina falling number was strongly correlated to wheat falling number ($r = 0.96$). When semolina falling number values were converted to liquefaction numbers, a strong correlation ($r = 0.98$) to semolina α-amylase activity was obtained, confirming that semolina liquefaction number is an excellent estimator of semolina α-amylase activity.

An alternative to falling number, widely used by Japanese pasta manufacturers for estimation of semolina α-amylase activity, is amylograph peak viscosity. Semolina does not disperse well in the amylograph, resulting in poor discrimination between samples, because lower than expected values are obtained (Table V). However, when the semolina is reduced into flour before amylograph analysis, as is the normal practice in Japan, the amylograph is effective in differentiating between samples with different α-amylase activity (Table V). Amylograph mobilities of semolina reduced into flour exhibited a high correlation ($r = 0.94$) to semolina α-amylase activity.

TABLE IV
α-Amylase Activity (units/g) of Durum Wheat Carlot Composites, Semolina, and Spaghetti[a]

Sample	Wheat	Semolina	Spaghetti Dried at 39°C	Spaghetti Dried at 70°C
1	4.8	1.8	2.0	1.8
2	5.9	2.2	2.0	1.7
3	9.6	6.0	3.3	3.0
4	10.7	4.9	3.9	3.6
5	13.6	5.6	4.7	3.8
6	17.2	6.0	4.4	4.0
7	18.3	5.0	3.5	5.5
8	20.9	15.3	9.0	5.2
9	23.9	12.8	9.6	5.2
10	42.0	23.8	14.4	12.7
11	45.6	16.6	12.3	6.9
12	51.2	21.8	15.2	12.3
13	53.8	22.3	16.2	13.8
14	58.4	32.2	18.0	13.6
15	63.8	39.6	19.9	18.4
16	74.8	33.8	25.2	18.2
17	80.7	47.9	26.5	19.7
18	82.5	48.4	25.9	22.4
19	99.8	48.1	31.7	24.4
20	111.7	65.2	34.0	28.6
21	113.5	42.4	33.3	30.2
22	116.2	51.0	33.7	27.2
23	117.8	59.9	33.7	25.4
24	136.2	59.4	17.9	14.5
25	141.3	69.2	36.6	25.6
26	147.2	49.6	40.4	29.5
27	186.3	89.2	48.8	41.5
28	214.6	71.5	54.5	46.7
29	295.5	133.9	90.0	68.4
30	676.2	297.6	240.3	146.6
Mean	101.1	46.1	30.4	22.7

[a] Results expressed on 14% mb.

Reducing Sugar Content of Semolina and Spaghetti

The reducing sugar content of semolina (Table VI) was significantly correlated ($P < 0.01$) to semolina α-amylase activity ($r = 0.71$) in agreement with previous reports (Kruger and Matsuo 1982, Matsuo et al 1982a). Similarly, the reducing sugar contents of spaghetti dried by both low- and high-temperature procedures were significantly ($P < 0.01$) correlated to semolina α-amylase activity ($r = 0.71$ and 0.68, respectively). However, the range of spaghetti reducing sugar contents among samples was relatively small, the difference in reducing sugar content between semolina and spaghetti was essentially constant for all samples, and there was no significant difference ($P > 0.05$) in spaghetti reducing sugar content attributable to drying procedure.

It has been shown that for spaghetti produced from semolina from sound durum wheat, the increase in reducing sugars during spaghetti processing occurs almost exclusively during extrusion, presumably due to shearing (Dexter et al 1981, Lintas and D'Appolonia 1973). Results from this study demonstrated that the relatively low moisture content of pasta dough and the rapid loss of moisture in spaghetti during the initial stages of drying limit the action of α-amylase during spaghetti processing regardless of drying procedure. Differences in spaghetti quality attributable to sprout damage will reflect the extent of starch modification by α-amylase in the semolina and are not magnified by further α-amylase action during processing.

Spaghetti Breaking Strength

Spaghetti breaking strength was significantly affected by drying temperature ($P < 0.05$), because the spaghetti dried at low temperature was weaker one week after processing than the spaghetti dried at high temperature (Table VII). Three months after processing there was no significant difference in spaghetti breaking strength ($P > 0.05$) attributable to drying temperature. For spaghetti dried by both drying procedures, breaking strength increased markedly ($P < 0.01$) between one week and three months of storage time.

It is widely believed by commercial pasta manufacturers (Combe et al 1988, Donnelly 1980, Maier 1980) that pasta produced from sprouted durum wheat semolina has inferior storage stability, but this was not evident in the current study (Table VII). Sample 30, which was badly sprouted, exhibited slight checking right out of the drier for both drying cycles. Three months later the checking, although still slight, was noticeably worse. None of the other samples showed any evidence of checking, including sample 29, which also had a wheat falling number of 60 sec but contained less than half the α-amylase activity of sample 30. There was no significant difference ($P > 0.05$) in breaking strength among samples, and the spaghetti processed from the most sprouted wheat (samples 28 to 30) actually ranked as the strongest.

All of the samples extruded evenly, and none showed any tendancy to stretching during drying. On the basis of these results, spaghetti processing behavior, strength, and storage stability were not influenced by sprout damage except in extreme cases.

Spaghetti Cooking Score

Spaghetti cooking score, a measure of spaghetti firmness and resilience, was strongly influenced ($P < 0.01$) by drying procedure and storage time (Table VII). The superior cooking quality of the spaghetti dried at 70°C was expected. The beneficial effect of high-temperature drying on spaghetti firmness and resilience has been well documented and is a primary reason for its rapid commercial acceptance in recent years (Abecassis et al 1984; Dexter et al 1981, 1983b; Wyland and D'Appolonia 1982). The improvement in spaghetti cooking quality with storage time has been observed in our laboratory in the past (unpublished reports). The cooking quality improvement is pronounced during the first few days after drying, and we routinely store spaghetti for one week prior to cooking quality assessment. As seen in Table VII, the cooking quality improvement observed for spaghetti stored three months over spaghetti stored one week, although highly significant, was slight. Further, the absence of a significant sample $\times$ storage time interaction term in the analysis of variance verified that all samples responded to storage time similarly.

There was no significant effect ($P > 0.05$) of sample on spaghetti cooking score, indicating that spaghetti firmness and resilience were not influenced by α-amylase activity regardless of drying procedure. As seen in Table VII, the two most badly sprouted samples (29 and 30) ranked near the middle in overall cooking score along with the three least sprouted samples (1, 2, and 3). Previously, we reported (Matsuo et al 1982a) that at high α-amylase activity spaghetti dried at low temperature may become slightly softer. The effect may have been attributable to differences in protein content between samples. In our previous study, the most sprouted samples were lowest in protein content. In the current study, protein content was constant.

Spaghetti Stickiness

Spaghetti dried at 70°C was less sticky ($P < 0.01$) than spaghetti dried at 39°C (Table VIII), in agreement with numerous previous reports (Abecassis et al 1984; Dexter et al 1981, 1983b). Spaghetti stickiness was not significantly influenced ($P > 0.05$) by storage time.

The effect of α-amylase activity on cooked spaghetti stickiness has not been documented previously in the literature. Some Japanese pasta manufacturers have reported that stickiness can be induced by sprout damage (private communications). In the current study, the effect of α-amylase on spaghetti stickiness was not significant ($P > 0.05$). In fact, the most sprouted sample (30) was the least sticky overall, whereas two of the soundest samples (2 and 3) were among the most sticky (Table VIII).

TABLE V
Semolina Falling Number (FN), Liquefaction Number, and Amylograph Peak Viscosity, and Flour Amylograph Peak Viscosity and Mobility for Durum Wheat Carlot Composites[a]

	Semolina			Flour[b] Amylograph	
Sample	Falling Number (sec)	Liquefaction Number (6000/[FN−50])	Amylograph Viscosity (BU)	Viscosity (BU)	Mobility (1,000/AV[c])
1	515	12.9	320	675	1.5
2	532	12.4	335	578	1.7
3	468	14.4	338	445	2.2
4	502	13.3	358	445	2.2
5	455	14.8	258	378	2.6
6	445	15.2	278	385	2.6
7	465	14.4	300	420	2.4
8	380	18.2	115	220	4.6
9	390	17.6	148	255	3.9
10	330	21.4	770	160	6.2
11	358	19.5	118	232	4.3
12	325	21.8	58	155	6.4
13	328	21.6	75	160	6.2
14	295	24.5	35	92	10.9
15	272	27.0	25	78	12.8
16	300	24.0	33	95	10.5
17	270	27.3	20	68	14.7
18	265	27.9	28	62	16.1
19	245	30.8	15	58	17.2
20	238	31.9	23	48	20.8
21	255	29.3	18	55	18.2
22	252	29.7	18	60	16.7
23	235	32.4	15	50	20.0
24	328	21.6	60	148	6.8
25	238	32.0	0	48	20.8
26	228	33.7	8	52	19.2
27	232	33.0	8	40	25.0
28	205	38.7	0	40	25.0
29	175	48.0	8	28	35.7
30	105	109.0	0	18	55.6
Mean	321	27.3	103	185	13.1

[a] Results expressed on 14% mb.
[b] Flour was prepared from semolina by gradual reduction using an Allis-Chalmers mill roll stand equipped with smooth frosted rolls.
[c] Amylograph viscosity.

TABLE VI
Reducing Sugar Content of Semolina and Spaghetti from Durum Wheat Carlot Composites[a]

Sample	Reducing Sugars (mg/g) Semolina	Spaghetti Dried at 30°C	Spaghetti Dried at 70°C
1	12.4	36.6	30.5
2	12.5	35.6	30.5
3	13.2	36.1	33.3
4	14.7	35.7	31.1
5	13.4	38.5	32.3
6	13.7	36.5	31.5
7	11.5	37.6	35.6
8	15.5	35.4	33.9
9	11.6	35.4	33.5
10	12.4	36.6	33.5
11	11.8	36.2	36.8
12	11.4	36.8	38.5
13	11.6	36.9	37.0
14	12.9	35.4	36.1
15	13.6	35.9	36.4
16	12.5	34.0	35.0
17	13.3	35.2	38.1
18	13.8	36.3	39.9
19	12.9	34.3	38.9
20	12.6	36.6	39.5
21	15.4	36.4	38.2
22	14.4	35.9	38.6
23	16.4	35.7	36.9
24	11.5	34.9	37.1
25	13.1	37.4	40.0
26	14.8	35.5	39.7
27	12.4	38.7	42.0
28	18.7	38.8	39.4
29	14.2	41.2	40.4
30	21.7	42.5	42.1
Mean	13.7	36.6	36.5

[a] Results expressed on 14% mb.

Spaghetti Cooking Loss

The effects of sample, drying temperature, and storage time on cooking loss were all highly significant ($P < 0.001$). The lower cooking loss of the spaghetti dried at high temperature was consistent with numerous previous reports (Dexter et al 1981, 1983b; Wyland and D'Appolonia 1982). Some samples were influenced more by drying procedure than others, as revealed by a significant sample × temperature interaction term in the analysis of variance. The lower cooking loss of the samples stored for three months was consistent with previous experience in our laboratory (*unpublished*).

The significant differences ($P < 0.001$) in cooking loss between samples were at least partially attributable to differences in α-amylase activity. The mean of cooking loss at both storage times was significantly correlated ($P < 0.01$) to semolina α-amylase activity for spaghetti dried both at low temperature ($r = 0.39$) and high temperature ($r = 0.41$). Eleven of the 12 samples with the highest overall mean cooking loss for all temperature and storage treatments had wheat falling numbers below 150 sec. However, semolina α-amylase activity acounted for less than 20% of the variance in cooking loss in both cases, and the range of mean cooking loss considering all storage and drying treatments between samples was only about 1.3%, rendering the effect of minimal quality importance. The slight effect of α-amylase activity on spaghetti cooking loss observed in the current study is consistent with the recent report of Combe et al (1988) who concluded that cooking loss was greater in spaghetti prepared from semolina from badly sprouted durum wheat.

CONCLUSIONS

This study corroborates previous reports concluding that sprout damage and associated α-amylase activity have minimal effects on spaghetti processing properties and cooking properties (Combe et al 1988, Dick et al 1974, Matsuo et al 1982a). With the exception of one badly sprouted sample, which was slightly checked, all

TABLE VII
Breaking Strength and Cooking Score of Spaghetti Dried at 39 and 70°C After Storing One Week and Three Months

Sample	Breaking Strength (N/m^b) of Spaghetti Dried at 39°C 1 Week	39°C 3 Months	70°C 1 Week	70°C 3 Months	Cooking Score (units) of Spaghetti Dried at 39°C 1 Week	39°C 3 Months	70°C 1 Week	70°C 3 Months
1	43.0	66.3	48.9	55.8	26.8	28.0	37.7	33.8
2	38.5	58.0	52.5	56.9	18.9	26.3	32.2	43.1
3	43.6	59.9	47.6	59.2	20.2	24.6	38.3	40.9
4	39.1	58.8	42.7	57.2	22.1	31.0	36.6	45.4
5	40.8	54.5	47.7	57.2	22.6	29.8	35.3	41.2
6	42.5	59.5	44.4	53.8	21.0	31.4	41.0	46.5
7	37.7	60.3	46.7	52.7	20.6	24.2	26.8	35.6
8	36.9	58.0	48.6	51.5	21.5	29.3	32.5	36.2
9	37.8	58.3	44.8	48.3	20.8	26.3	28.4	39.1
10	39.0	60.8	43.9	48.7	24.0	27.2	33.7	42.1
11	38.8	58.0	48.0	52.6	23.2	32.0	28.2	28.6
12	40.8	58.3	50.0	50.4	24.4	28.6	30.8	28.8
13	43.6	65.2	54.8	57.1	27.3	31.0	35.3	35.4
14	38.6	60.4	54.0	56.5	21.6	28.3	34.2	35.2
15	39.4	56.6	53.5	53.3	23.1	27.6	36.9	38.8
16	42.6	57.5	49.9	54.5	25.1	28.3	28.3	41.0
17	50.6	53.2	55.1	53.9	26.7	29.4	39.7	40.4
18	53.0	54.1	52.4	57.3	29.6	29.0	37.6	42.8
19	48.2	49.6	49.3	54.5	26.8	29.1	30.2	32.9
20	50.3	54.8	48.6	52.6	26.0	26.9	37.9	37.8
21	50.1	54.1	45.2	53.9	27.3	30.5	34.7	33.5
22	51.7	55.8	46.4	54.4	28.5	30.5	34.8	32.6
23	50.6	50.6	45.5	52.8	27.4	27.4	28.4	28.0
24	47.1	54.7	48.0	55.7	25.1	33.2	34.9	36.6
25	48.9	59.6	47.4	57.5	25.5	23.9	34.2	31.8
26	47.4	58.3	50.5	60.8	24.0	25.7	28.4	36.0
27	45.6	58.1	55.0	61.1	20.7	16.4	29.2	36.6
28	49.0	56.6	57.0	62.0	24.6	23.5	33.4	35.9
29	48.7	57.8	56.9	61.8	25.3	23.2	34.0	37.9
30	49.0	55.9	58.7	60.8	23.2	24.7	32.3	43.0
Mean	44.5	57.4	49.8	55.5	24.1	27.6	33.5	37.2

TABLE VIII
Stickiness and Cooking Loss of Spaghetti Dried at 39°C and 70°C After Storing One Week and Three Months

Sample	Stickiness (N/m^b) of Spaghetti Dried at				Cooking Loss (%) of Spaghetti Dried at			
	39°C		70°C		39°C		70°C	
	1 Week	3 Months	1 Week	3 Months	1 Week	3 Months	1 Week	3 Months
1	770	860	725	810	6.9	6.7	5.7	5.2
2	825	785	825	835	7.1	6.8	5.9	5.4
3	805	945	800	835	7.6	6.9	6.2	6.5
4	790	815	715	745	7.2	6.8	5.9	5.5
5	790	790	835	745	7.3	7.1	6.1	5.6
6	800	880	670	740	7.4	6.9	5.8	5.7
7	805	790	810	820	7.4	7.2	6.5	6.3
8	835	790	795	865	7.4	7.4	6.6	6.5
9	800	770	790	865	7.6	7.6	6.6	6.3
10	820	825	715	850	7.1	7.2	6.4	5.6
11	795	725	740	825	7.3	6.5	6.5	6.3
12	760	775	745	830	7.4	6.9	7.0	6.7
13	790	875	770	790	5.6	6.5	6.7	6.1
14	860	770	790	828	7.4	6.4	6.4	6.3
15	840	865	800	818	7.1	6.6	6.4	6.5
16	760	825	740	815	7.3	6.8	6.9	6.3
17	790	840	740	690	7.5	6.8	6.3	5.8
18	855	800	760	650	6.9	6.5	6.4	6.3
19	790	795	745	750	7.5	6.6	7.0	6.8
20	830	820	840	850	7.7	6.8	7.4	7.1
21	800	800	785	855	7.3	6.8	7.6	7.8
22	825	780	690	845	7.5	6.5	7.1	7.7
23	760	830	770	825	7.2	6.6	7.3	7.0
24	840	810	765	740	7.0	6.6	6.7	6.3
25	770	725	830	790	7.4	6.9	7.2	7.1
26	800	835	700	815	7.7	6.9	6.9	6.8
27	810	810	810	760	7.8	6.9	7.7	7.3
28	795	860	705	785	7.6	6.8	6.8	6.8
29	825	830	775	780	8.1	7.2	6.8	6.7
30	725	735	800	705	8.0	7.2	6.9	6.7
Mean	802	812	766	795	7.3	6.8	6.7	6.4

the samples in the current study processed normally. There was no evidence that α-amylase activity had any influence on storage stability, as measured by spaghetti strength and cooking quality. Regardless of whether spaghetti was dried by low or high temperature, neither spaghetti firmness nor spaghetti stickiness was affected by sprout damage. Although cooking loss increased slightly when wheat falling number fell below 150 sec, the effect was too slight to be of concern to commercial processors.

The action of α-amylase during spaghetti processing appears to be limited by the low water content of pasta doughs. Spaghetti contains a greater level of reducing sugars than semolina, but this results almost exclusively from shearing during extrusion (Dexter et al 1981, Lintas and D'Appolonia 1973) rather than α-amylase action. In the current study, the amount of reducing sugars formed during processing was not related to semolina α-amylase activity or to spaghetti drying temperature. α-Amylase action during cooking is limited by rapid denaturation by the penetrating boiling cooking water (Kruger and Matsuo 1982).

ACKNOWLEDGMENTS

Wheat samples were graded by L. R. Jamison of the Canadian Grain Commission Grain Inspection Division. The expert technical assistance of J. J. Lachance, L. J. Morris, R. W. Daniel, N. M. Edwards, M. Lymych, D. A. Daniel, J. Burrows, and G. Shimizu is gratefully acknowledged.

LITERATURE CITED

ABECASSIS, J., ALARY, R., and FEILLET, P. 1984. Influence des temperatures de séchage sur l'aspect et la qualité culinaire des pâtes alimentaires. Ind. Céréles 31(7):13.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Method 08-01, revised 1976; Method 22-10, approved 1960. The Association: St. Paul, MN.

AUTRAN, J.-C., ABECASSIS, J., and FEILLET, P. 1986. Statistical evaluation of different technological and biochemical tests for quality assessment in durum wheats. Cereal Chem. 63:390.

AXFORD, D. W. E., McDERMOTT, E. E., and REDMOND, D. G. 1978. Small-scale tests of breadmaking quality. Milling 161(5):18.

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

BLACK, H. C. 1966. Laboratory purifier for durum semolina. Cereal Sci. Today 11:533.

BLACK, H. C., HSIEH, F.-H., TIPPLES, K. H., and IRVINE, G. N. 1980. The GRL sifter for laboratory flour milling. Cereal Foods World 12:757.

BUCHANAN, A. M., and NICHOLAS, E.M. 1980. Sprouting, alpha-amylase, and bread-making quality. Cereal Res. Commun. 8:23.

CANADIAN GRAIN COMMISSION. 1988. Official Grain Grading Guide. Office of the Chief Grain Inspector, Inspection Division, Canadian Grain Commission: Winnipeg, MB, Canada.

COMBE, D., GARCON-MARCHAND, O., SEILLER, M.-P., and FEILLET, P. 1988. Influence de la germination sur la qualité des blés durs. Ind. Céréales 53(3):29.

CORR, J.G., and SPILLANE, P.A. 1969. Some factors affecting amylolytic behavior in Irish flours. J. Sci. Food Agric. 20:638.

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

DEXTER, J. E., and MATSUO, R. R. 1982. Effect of smudge and blackpoint, mildewed kernels, and ergot on durum wheat quality. Cereal Chem. 59:63.

DEXTER, J. E., MATSUO, R. R., KOSMOLAK, F. G., LEISLE, D., and MARCHYLO, B. A. 1980. The suitability of the SDS-sedimentation test for assessing gluten strength in durum wheat. Can. J. Plant Sci. 60:427.

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

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

DEXTER, J. E., MATSUO, R. R., and MORGAN, B. C. 1983b. Spaghetti stickiness: Some factors influencing stickiness and relationship to other

cooking quality characteristics. J. Food Sci. 48:1545.
DEXTER, J. E., MATSUO, R. R., LACHANCE, J. J., MORGAN, B. C., and DANIEL, R. W. 1985a. Veranderungen am Programm zur Beurteilung der Durum Weizenqualität der kanadischen Getreideforshungsanstalt. Getreide Mehl Brot 39:131.
DEXTER, J. E., MATSUO, R. R., and MacGREGOR, A. W. 1985b. Relationship of instrumental assessment of spaghetti cooking quality to the type and amount of material rinsed from cooked spaghetti. J. Cereal Sci. 3:39.
DEXTER, J. E., MATSUO, R. R., and MARTIN, D. G. 1987. The relationship of durum wheat test weight to milling performance and spaghetti quality. Cereal Foods World 32:772.
DEXTER, J. E., MARTIN, D. G., and MATSUO, R. R. 1988. The effect of roll flute orientation on durum wheat experimental milling performance and semolina quality. Can. Inst. Food Sci. Tech. J. 21:187.
DEXTER, J. E., MATSUO, R. R., and DANIEL, R. W. 1989. The influence of heat damage on durum wheat spaghetti quality. Can. Inst. Food Sci. Tech. J. 22:227.
DICK, J. W., and QUICK, J. S. 1983. A modified screening test for the rapid estimation of gluten strength in early-generation durum wheat breeding lines. Cereal Chem. 60:315.
DICK, J. W., WALSH, D. E., and GILLES, K. A. 1974. The effect of sprouting on the quality of durum wheat. Cereal Chem. 51:180.
DONNELLY, B. J. 1980. Effect of sprout damage on durum wheat quality. Macaroni J. 62(7):8.
DYGERT, S., LI, H., FLORIDA, D., and THOMA, J. A. 1965. Determination of reducing sugar with improved precision. Anal. Biochem. 13:367.
FINNEY, K. F., NATSUAKI, O., BOLTE, L. C., MATHEWSON, P. R., and POMERANZ, Y. 1981. Alpha-amylase in field-sprouted wheats: Its distribution and effect on Japanese-type sponge cake and related physical and chemical tests. Cereal Chem. 58:355.
HAGBERG, S. 1961. Note on a simplified rapid method for determining alpha-amylase activity. Cereal Chem. 38:202.
HENRY, R. J., MARTIN, D. J., and BLAKENEY, A. B. 1987. Reduction of the alpha-amylase content of sprouted wheat by pearling and milling. J. Cereal Sci. 5:155.
HLYNKA, I. 1968. Amylograph mobility and liquefaction number. Cereal Sci. Today 13:245.
HOOK, S. C. W. 1984. Specific weight and wheat quality. J. Sci. Food Agric. 35:1136.
IBRAHIM, Y., and D'APPOLONIA, B. L. 1979. Sprouting in hard red spring wheat. Baker's Dig. 53(5):17.
KRUGER, J. E. 1981. Severity of sprouting as a factor influencing the distribution of alpha-amylase in pilot mill streams. Can. J. Plant Sci. 61:817.
KRUGER, J. E., and MATSUO, R. R. 1982. Comparison of alpha-amylase and simple sugar levels in sound and germinated durum wheat during pasta processing and spaghetti cooking. Cereal Chem. 59:26.
KRUGER, J. E., and REED, G. 1988. Enzymes and color. Pages 441-500 in: Volume I, Wheat: Chemistry and Technology, 3rd ed. Y. Pomeranz, ed. American Association of Cereal Chemists: St. Paul, MN.
KRUGER, J. E., and TIPPLES, K. H. 1979. Relationship between falling number, amylograph viscosity and alpha-amylase activity in Canadian wheat. Proc. Int. Sprouting Symp. 2nd M. D. Gale and V. Stoy, eds. Cereal Res. Commun. 8:97.
KRUGER, J. E., and TIPPLES, K. H. 1981. Modified procedure for use of the Perkin-Elmer model 191 grain amylase analyzer in determining low levels of alpha-amylase in wheats and flours. Cereal Chem. 58:271.
LINTAS, C., and D'APPOLONIA, B. L. 1973. Effect of spaghetti processing on semolina carbohydrates. Cereal Chem. 50:563.
MAIER, M. G. 1980. Wide spread sprout damage. Macaroni J. 62(10):20.
MATSUO, R. R. 1978. Note on a method for testing gluten strength. Cereal Chem. 55:259.
MATSUO, R. R., and DEXTER, J. E. 1980. Comparison of experimentally milled durum wheat semolina to semolina produced by some Canadian commercial mills. Cereal Chem. 57:117.
MATSUO, R. R., DEXTER, J. E., and DRONZEK, B. L. 1978. Scanning electron microscopy study of spaghetti processing. Cereal Chem. 49:707.
MATSUO, R. R., DEXTER, J. E., and MacGREGOR, A. W. 1982a. Effect of sprout damage on durum wheat and spaghetti quality. Cereal Chem. 59:468.
MATSUO, R. R., DEXTER, J. E., KOSMOLAK, F. G., and LEISLE, D. 1982b. Statistical evaluation of tests for assessing spaghetti-making quality of durum wheat. Cereal Chem. 59:222.
MATVEEF, M. 1963. Recherche sur les blés durs germés du point de vue de leur utilisation dans l'industrie. Bull. Ecole Franc. Meun. 198:307.
MEREDITH, P., and POMERANZ, Y. 1985. Sprouted grain. Adv. Cereal Sci. Technol. 7:239-320.
PERTEN, H. 1964. Application of the falling number method for evaluating alpha-amylase activity. Cereal Chem. 41:127.
QUICK, J. S., and DONNELLY, B. J. 1980. A rapid test for estimating durum wheat gluten quality. Crop Sci. 20:816.
TIPPLES, K. H. 1971. A note on sample size error in the falling number test. Cereal Chem. 48:85.
TIPPLES, K. H., KILBORN, R. H., and BUSHUK, W. 1966. Effect of malt and sprouted wheat on baking. Cereal Sci. Today 11:362.
WILLIAMS, P. C. 1973. The use of titanium dioxide as a catalyst for large-scale Kjeldahl determination of total nitrogen content of cereal grains. J. Sci. Food Agric. 24:243.
WILLIAMS, P. C., STEVENSON, S. G., and IRVINE, G. N. 1978. Testing wheat for protein and moisture with the automated digital analyzer. Cereal Chem. 55:263-279.
WYLAND, A. R., and D'APPOLONIA, B. L. 1982. Influence of drying temperature and farina blending on spaghetti quality. Cereal Chem. 59:199.

[Received September 19, 1989. Accepted March 1, 1990.]