Effect of High-Temperature Drying of Pasta on Quality Parameters and on Solubility, Gel Electrophoresis, and Reversed-Phase High-Performance Liquid Chromatography of Protein Components[1]

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Cereal Chem. 69(3):288–295

ABSTRACT

Spaghetti made from durum wheats with weak (Rugby) and strong (Vic) gluten was dried at high temperatures of 70, 80, and 90°C and compared with spaghetti given conventional low-temperature drying at 40 and 60°C. Protein denaturation, measured by loss of solubility in dilute acetic acid, increased significantly in both varieties as drying temperature increased. Generally, the color score of dried spaghetti increased. Cooked weight increased, cooking loss decreased, and firmness generally increased as drying temperature increased. Other effects of increased drying temperature were a significant increase in residue proteins and a decrease in proteins of other classes of the Osborne solubility procedure. A decrease or an increase in intensity of some bands in the gel electrophoresis patterns of certain fractions was observed; however, the gliadin fraction was most stable to high-temperature drying. High-temperature drying affected the retention times and peak areas of reversed-phase high-performance liquid chromatography peaks of gliadins, mainly from the spaghetti dried at 90°C.

According to Gilles et al (1966) and Banasik (1981), the most difficult and critical step in the processing of pasta products is drying. The objective of drying is to lower the moisture content of the product from 31% to 19 or 13% so that the pasta will be translucent, retain its shape, and store without shattering. When the drying is too slow, pasta products tend to spoil or become moldy, but when the drying is too rapid, moisture gradients occur that cause the products to crack or check. This can occur either during the drying period or afterwards, even after pasta has been packaged and sold.

Hoskins and Hoskins (1959) reported that if drying time could be reduced and the reliability of the process increased, a considerable saving in space and possibly in equipment cost could be realized. They also found that pasta products can be dried more rapidly without checking by using high-temperature drying. Some researchers in Europe and the United States indicate that possibly even shorter drying times may be realized by the high-temperature drying methods. The reason for shorter drying time at high temperature is that the moisture may diffuse more rapidly within the strand of macaroni product.

High-temperature drying of pasta products is now being used in many commercial applications (Buhler-Miag Inc. 1979; Pavan 1979, 1980; Braibanti, C.S.P.A. 1980). Several researchers have evaluated the quality of high-temperature-dried pasta products (Ibrahim 1982; Wyland and D'Appolonia 1982; Dexter et al 1983a,b; Pagani et al 1986; Berglund et al 1987; Mok 1988). Most results show an improvement in color, better firmness, lower cooking loss, higher cooked weight, and less stickiness. The effects of high-temperature drying on color and cooking quality depend on both the raw material and drying conditions. In particular, the water activity of the pasta at the time of application of high temperature and the duration of high temperature are critical to pasta properties (Dexter et al 1981, 1984; Baroni 1988; Feillet 1988).

The purpose of the present study, therefore, was to characterize the protein components of spaghetti dried at different temperatures by various biochemical techniques to gain information on any changes in properties of the proteins such as charge, size, surface hydrophobicity, and solubility distribution.

MATERIALS AND METHODS

Wheat Samples

The durum wheat varieties used in this study, Vic and Rugby, were field plot samples grown at Langdon, Minot, and Carrington, ND, during the 1989 crop year and were chosen for their strong and weak gluten characteristics, respectively.

Milling Procedure

Both varieties of wheat were cleaned by passing the grain through a Carter dockage tester (Carter-Day Co., Minneapolis, MN). The wheat samples were tempered and milled on a Buhler laboratory mill (Buhler-Miag, Minneapolis, MN) equipped throughout with corrugated rolls according to the procedure of Seyam et al (1974). Semolina was purified on a Miag laboratory purifier. The semolina extraction rate was 61.9% for Vic and 58.7% for Rugby.

Pasta Processing

All samples were processed into spaghetti according to procedures at the Cereal Science and Food Technology Department, North Dakota State University, as follows: The amount of water to be added to semolina to obtain an absorption of 31.5% was calculated. A 1,000-g sample of each semolina was mixed and extruded. The proper amount of distilled water, at 40°C, was added slowly during mixing at slow speed in a Hobart Mixer

[1]Published with the approval of the director, Agricultural Experiment Station, North Dakota State University, as Journal Series 2004.

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(Hobart Manufacturing Co., Troy, OH) equipped with a special mixing paddle. After all the water was added, the sample was mixed at high speed until uniformly mixed and was transferred to the vacuum mixer of a Demaco semicommercial scale vacuum pasta extruder. The dough was pressed through an 84-strand Teflon spaghetti die with a 0.157 cm diameter. The following conditions were used for dough extrusion: screw rotation speed, 19 rpm; vacuum, 457 mm of Hg; meter jacket temperature, 47°C. Each semolina sample was extruded in triplicate.

Pasta Drying

The extruded spaghetti samples were dried in a laboratory pilot-scale pasta drier, model 300 (Standard Industries, Inc., Fargo, ND). Five drying cycles were used for this study: two conventional low-temperature cycles of 40 and 60°C and three high-temperatures (HT) cycles of 70, 80, and 90°C (Fig. 1). For the 40°C conventional low-temperature drying cycle, the extruded spaghetti was dried for a total of 18 hr. The temperature was held constant at 40°C for the first 10 hr of the drying cycle (Fig. 1A), then slowly decreased over the remaining 8 hr to 30°C. Relative humidity (rh) was lowered gradually from 80% at the beginning to 40% at the end of the drying cycle (Gilles et al 1966).

At stage I of the 60°C drying cycle (Fig. 1B), the temperature was increased in the first hour from the starting conditions of 20°C and 78% rh to 55°C and 80% rh and then was held for 3 hr. At stage II, the relative humidity remained constant at 80% while the temperature was increased to the final temperature of 60°C. These conditions were maintained for a period of 8.5 hr, followed by a cool-down period of 2 hr, while the temperature was lowered to 30°C and relative humidity to 50%. Overnight equilibration was allowed at 30°C and 50% rh to strengthen the spaghetti.

The first stage of the 70 and 80°C drying cycles (Fig. 1C and D, respectively) was the same as that of the 60°C procedure.

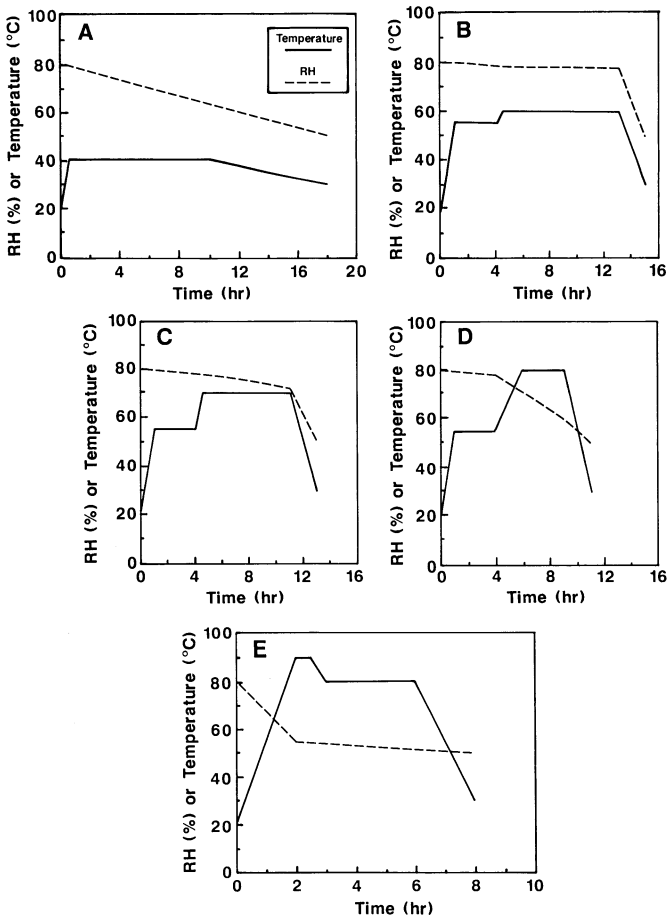

Fig. 1. Drying curves of spaghetti processed from Vic and Rugby semolina. **A–E,** Spaghetti dried at 40, 60, 70, 80, and 90°C, respectively.

The second stage of the 70°C drying cycle (Fig. 1C) was 6.5 hr long, with the temperature held constant at 70°C and the relative humidity at 80%. The second stage of the 80°C drying cycle (Fig. 1D) was 3 hr long, with the temperature held constant at 80°C and the relative humidity at 80%. These conditions were followed by a cool-down period (2 hr), returning the temperature to 30°C and relative humidity to 50% in both 70 and 80°C drying cycles. Overnight equilibration was allowed at 30°C and 50% rh to strengthen the spaghetti.

During the first stage of the 90°C drying cycle (Fig. 1E), the temperature increased from 20 to 90°C in 2 hr, at a relative humidity of 78%. The temperature was held at 90°C for a half hour and then decreased to 80°C in a half hour. During the second stage, the temperature was held constant at 80°C for 3 hr, then decreased from 80 to 40°C in 2 hr followed by a cool-down period of 2 hr, returning the temperature to 30°C and the relative humidity to 50%. Overnight equilibration was allowed at 30°C and 50% rh to strengthen the spaghetti. Relative humidity was held at 78% in the first stage, then rapidly decreased to 40% because during the first hour, humidity could not be controlled properly due to equipment limitations.

Spaghetti Analysis

Spaghetti color scores were determined by light reflectance using a Hunter Color Difference Meter model D25 (Hunter Associates Laboratory, Inc., Reston, VA) according to the procedure of Walsh (1970).

Spaghetti was cooked according to the procedure of Dick et at (1974). Cooked weight was determined by weighing the drained and rinsed spaghetti and reporting the values obtained in grams. To determine cooking loss, the combined cooking and rinse waters were collected in a tared beaker, placed in an air-oven at 100°C and evaporated to dryness. The residue was weighed and reported as a percentage of the original spaghetti sample.

Firmness was measured on two strands of spaghetti as described by Walsh (1971) with an Instron Universal Testing Instrument, type T (Instron Corp., Canton, MA).

Gluten Denaturation

Gluten denaturation was determined by adapting the method of Pence et al (1953) as described by Kim (1981). For the determination, 2.0 g of semolina (as is), was wetted with 4 ml of isopropanol and extracted with 40 ml of 0.1*N* acetic acid in a 50-ml plastic centrifuge tube on a mechanical shaker (Wrist-action, Burrel Corp., Pittsburg, PA) for 1 hr at setting 10. After centrifugation at 5,000 × *g* for 30 min at 5°C, 20 ml of the supernatant was analyzed for nitrogen by the macro-Kjeldahl method (AACC 1983, Method 46-11) using 1 ml of antifoam agent (antifoam A emulsion, Sigma Chemical Co., diluted 1:4 with diethyl ether) to prevent foaming during digestion. Digestion was done first at a low heat setting to boil off the water and then at full heat for 40 min.

Protein Fractionation

A modified Osborne solubility fractionation procedure reported by Chen and Bushuk (1970) was applied. A 10-g sample of ground semolina or ground spaghetti was sequentially extracted with 0.5*M* NaCl, 70% aqueous ethanol, and 0.05*M* acetic acid solutions to give four protein fractions: salt-soluble (albumin and globulin), ethanol-soluble (gliadin), acetic acid-soluble (glutenin), and residue. Albumins were separated from globulins by dialysis of the salt extract against distilled water. The protein content of all fractions (as is) was measured by the micro-Kjeldahl method (AACC 1983, Method 46-13). The protein distribution of each sample was calculated from the weight and protein content of each fraction.

Polyacrylamide Gel Electrophoresis

The albumin, globulin, and gliadin fractions were subject to polyacrylamide gel electrophoresis (PAGE), according to the procedure of Khan et al (1985, 1988). Proteins were prepared in aluminum lactate buffer (10 mg of gliadin, 30 mg of albumin,

or 20 mg of globulin per milliliter), and 10 or 30 μl of these samples were applied onto the gel, depending upon the fraction.

Sodium dodecyl sulfate (SDS)-PAGE was performed on the Osborne fractions (10 mg of protein per milliliter), according to a modified Laemmli (1970) procedure, on 12% (w/v) acrylamide (0.1%, w/v, bisacrylamide) resolving gels. A Hoefer SE600 vertical gel apparatus (Hoefer Scientific, San Francisco, CA) was used to make 1.5-mm thick gels, and 10 μl of sample was applied. Gels were electrophoresed for 3 hr at 50 mA per gel. The tracking dye, Pyronine Y, migrated off the gel during this time. Gels were then stained for 6 hr with 0.1% (w/v) Coomassie Brilliant Blue R250 in 10% (w/v) trichloracetic acid, 50% (v/v) methanol, and 10% (v/v) glacial acetic acid. Gels were destained in 40% (v/v) methanol and 7.5% (v/v) glacial acetic acid until the gel background was clear for photography.

Reversed-Phase High-Performance Liquid Chromatography

Reversed-phase high-performance (pressure) liquid chromatography (RP-HPLC) was done according to the modified procedure of Huebner and Bietz (1987). Wheat proteins were extracted from ground semolina or spaghetti samples with 70% aqueous ethanol on an equal-protein basis (0.082 mg/ml) for 1 hr with a 30-sec vortex every 10 min. Extracts were centrifuged at 20,000 × *g* for 20 min, and the supernatant was filtered using Gelman LC13 0.45-μm filters (Ann Arbor, MI). HPLC was performed with a Hewlett Packard model 1090 chromatograph (Hewlett-Packard, Minneapolis, MN), which consisted of a PV5 solvent delivery system, a filter photometric detector, and an HP 3393A computing integrator. Analyses were carried out with a SynChropak RP column (C18, 300 A pore size, 250 × 4.1 mm) preceded by a guard column of the same packing material (5 × 4.6 mm) (SynChrom Inc., Linden, IN). Gradients were generated with water containing 0.06% trifluoracetic acid (solvent A) and acetonitrile containing 0.05% trifluoracetic acid (solvent B). All solvents were filtered (0.45 μm), degassed, and sparged continuously with helium. The gradient began with 25% B, increased to 30% B at 5 min, and to 50% B at 55 min with a 5-min hold. Solvent B was then increased to 100% to wash the column and held there for 5 min before being returned to 25% at 75 min. There was a 5-min column equilibration at initial conditions between manual injections. Samples of 100 μl were injected, and a flow rate of 1 ml/min at 55°C was used. A wavelength of 210 nm was used to monitor the eluate.

Statistical Analysis

The data were analyzed statistically using the GLM procedure of the Statistical Analysis System (SAS Institute 1986). A split-plot design was employed, and the Duncan's multiple range test was applied to compare mean values.

RESULTS AND DISCUSSION

Drying Cycles

Figure 1A–E provides detailed information on the spaghetti drying cycles. The drying cycles for 60–90°C are similar to Buhler cycles (Ibrahim 1982), in which there is a stepwise increase to attain the final drying temperature. The 90°C cycle is also similar to a Buhler high-temperature cycle (their Turbothermatik cycle); however, due to equipment limitations, the gradual multistepwise increase in temperature over a 1- to 1.5-hr period could not be achieved. Therefore, a constant gradual increase to 90°C in a 2-hr period was adopted (Fig. 1E). These drying cycles are used at the Northern Crops Institute, Fargo, ND (Jim Jacobs, *personal communication*). These drying cycles are similar to the HT-B cycle of Dexter et al (1981), in which high temperature is reached after a preliminary lower drying temperature.

The initial moisture of spaghetti for all drying cycles was approximately 30%, diminishing to about 11–12.5% at the end of the drying cycles. The drop in moisture in these cycles follows the pattern of the HT-B cycle of Dexter et al (1981), in which the moisture drops to about 20% before the high temperature is reached and then the high temperature is held for the specified time before cooling begins. During this time, moisture gradually drops to its final value of about 11–12.5%. Resmini and Pagani (1983) refer to this type of cycle as HT-LM (high temperature-low moisture).

Protein Denaturation

The solubility of protein is considered an index of denaturation, with lower solubility indicating a higher degree of denaturation. Duncan's multiple range test showed that increasing the drying temperature caused a significant decrease in acetic acid-soluble protein (Table I). Compared to the solubility of the protein in the semolina, and in spaghetti dried at 40°C, both varieties of spaghetti dried at 60, 70, and 80°C showed a large degree of denaturation. At 90°C, there was even a greater degree of protein denaturation in the two varieties. Thus, at very-high-temperature drying at 90°C, a change must occur in the properties of the proteins, and this may partly explain the improved cooking quality (e.g., higher cooked weight and lower cooking loss) observed at this temperature (Aktan 1990).

Table I also shows that Vic, a strong gluten durum wheat, has a lower percentage of acetic acid-soluble proteins than Rugby, a weak gluten durum. There was also a significant difference in the acetic acid-soluble protein between the semolina and any of the spaghetti samples. These results agree with those of Dexter and Matsuo (1977), who observed an 8% decrease in protein solubility in acetic acid in spaghetti dried at a low temperature of 39°C, and with other studies (Cubadda and Resmini 1968, Dexter et al 1981, Ibrahim 1982). Dexter and Matsuo (1977)

TABLE I
Effects of Drying Temperature and Variety on Various Spaghetti Quality Parameters[a]

	Acetic Acid-Soluble Protein[b] (mean, %)	Quality Parameter			
		Color Score (mean)	Cooked Weight (mean, g)	Cooking Loss (mean, %)	Firmness (mean, g/cm)
Semolina	71.34 a	...	...	...	...
Drying temperature, °C					
40	66.87 b	9.75 b	29.17 c	7.68 a	8.41 a
60	65.62 c	9.75 b	29.44 c	7.90 a	8.04 b
70	64.82 c	9.75 b	29.56 c	6.65 b	8.41 a
80	63.36 d	9.75 b	30.68 b	6.55 b	8.42 a
90	46.67 e	10.75 a	31.61 a	6.20 b	8.10 b
Variety					
Vic	58.26 b	10.20 a	29.78 a	7.01 a	9.01 a
Rugby	67.96 a	9.70 b	30.41 a	6.98 a	7.54 b
LSD (0.05)[c]	1.92				

[a] Any two means followed by different letters differ significantly ($\alpha = 0.05$), by Duncan's multiple range test.
[b] A measure of protein denaturation.
[c] Least significant difference; comparison of two means.

TABLE II
Effects of Temperature and Variety on Percent of Total Protein of Fractions from the Modified Osborne Solubility Procedure of Chen and Bushuk (1970)[a]

	Fractions				
	Albumin (mean, %)	Globulin (mean, %)	Gliadin (mean, %)	Glutenin (mean, %)	Residue (mean, %)
Semolina	8.71 a	4.98 a	38.06 a	17.12 a	24.68 f
Drying temperature, °C					
40	8.65 a	2.19 b	37.78 a	14.50 b	30.95 e
60	8.60 a	1.96 b	36.86 a	14.49 b	33.24 d
70	8.42 ab	1.95 b	34.53 b	14.19 b	34.84 c
80	7.98 b	1.80 b	33.56 b	13.95 b	36.96 b
90	6.05 c	0.79 c	28.11 c	8.25 c	53.71 a
Variety					
Vic	8.05 a	2.09 a	32.95 a	10.86 a	41.00 a
Rugby	8.09 a	2.47 a	36.69 a	16.64 a	30.46 a
LSD (0.05)[b]	0.58	3.50	8.84	14.33	13.13

[a] Any two means followed by different letters differ significantly ($\alpha = 0.05$) by Duncan's multiple range test.
[b] Least significant difference; comparison of two means.

indicated that loss of protein solubility at 40°C was attributable to extrusion rather than to drying temperature.

Spaghetti Quality

The color of good quality spaghetti is expected to be amber yellow. Generally scores of 8.5 or higher reflect a bright amber product, whereas scores lower than 8.5 can indicate a dull amber, brown, gray, or white product. The two varieties showed good color scores (Table I). The spaghetti dried at high temperature (90°C) had a higher color score for both varieties than spaghetti dried at the other temperatures. The Duncan's test (Table I) showed that the spaghetti color score of Vic was significantly higher than that of Rugby. Our results agree with most studies, which show an increase in color with high-temperature drying (Manser 1980; Dexter et al 1981, 1984; Ibrahim 1982; Wyland and D'Appolonia 1982). Dexter et al (1981) stated that application of high temperature during the initial stages of the drying process is the most effective way to enhance spaghetti color intensity. Our results also agree with those reported by Kobrehel and Abecassis (1985), who showed that a drying temperature of 90°C improved the color of pasta.

Cooked weight at optimum cooking time (Table I) for the two varieties showed significant increases at drying temperatures of 80 and 90°C. Analysis of variance (results not shown) indicated that temperature had a significant effect on cooked weight; variety did not have a significant effect, but the interaction between variety and temperature did. The results of our study of cooked weight agree with those of Dexter et al (1981), who observed an increase in cooked weight with a higher drying temperature, using a drying procedure in which the high temperature was applied at the final stage of drying.

Cooking loss at optimum cooking time (Table I) showed no significant differences among spaghetti samples dried at temperatures up to 60°C; however, at 70°C there was a significant decrease in cooking loss, which remained relatively constant up to 90°C. Analysis of variance (results not shown) showed that temperature had a highly significant effect on cooking loss whereas variety did not. Our results agree with those of several investigators (Manser 1980; Dexter et al 1981, 1983a, 1984; Ibrahim 1982; Wyland and D'Appolonia 1982), who reported an improving effect on cooking loss with increase in drying temperature.

The variety Vic gave higher firmness values than the variety Rugby at optimum cooking time (Table I). Firmness at optimum cooking time showed a decrease at 60°C, an increase at 70°C, and then a decrease at 90°C. The analysis of variance (results not shown) of the firmness data showed that variety and drying temperature each had a significant effect on firmness. A significant decrease in firmness for the 90°C-dried spaghetti was observed. This decrease was most likely due to cracking and checking problems in the spaghetti dried at 90°C that resulted from the inability to adequately control humidity during the first stages of the 90°C drying process due to equipment limitations. Upon cooking, the 90°C-dried spaghetti lost its cylindrical shape and flattened out, resulting in thinner test pieces and a shorter path length for texture measurement, which resulted in lower firmness values. Therefore, assuming a cylindrical shape, the 90°C-dried spaghetti should have firmness values equal to or greater than the 80°C-dried spaghetti. Increases in firmness for spaghetti dried at high temperature have also been reported by Buhler-Miag, Inc. (1979), Pavan (1979), Dexter et al (1981, 1983a, 1984), Wyland and D'Appolonia (1982), Ibrahim (1982), and Mok (1988).

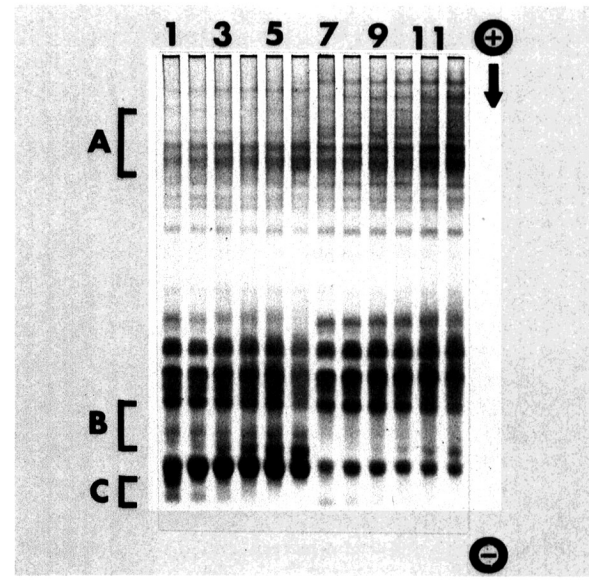

Fig. 2. Polyacrylamide gel electrophoresis patterns of albumin of Vic (patterns 1–6) and Rugby (patterns 7–12) samples: 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. A = low-mobility bands, B and C = high-mobility bands.

Protein Solubility Fractionation and Distribution

Protein distribution was obtained from the modified Osborne solubility fractionation procedure of Chen and Bushuk (1970). Duncan's multiple range test (Table II) showed that as drying temperature increased, the percentage of total protein of the albumin and glutenin fractions decreased significantly while that in the residue fraction increased significantly. Also, there were no significant differences in percent of total protein in the globulin and gliadin fractions of spaghetti dried at temperatures of 60, 70 and 80°C. These results are similar to those of Wasik (1978) for conventional dried spaghetti, except that he found a decrease in the globulin fraction instead of the albumin fraction. Analyses

of variance (results not shown) indicated that temperature had a significant effect on percent of total protein in fractions, whereas variety did not, but interaction between variety and temperature had a highly significant effect for both glutenin and residue fractions. Reduction in solubility as drying temperature increases may be a result of protein-starch interactions, as suggested by Resmini and Pagani (1983) from their scanning electron microscopy of spaghetti dried with high temperature and low moisture.

PAGE and SDS-PAGE of Protein Fractions

For the PAGE and SDS-PAGE studies, samples of equal protein content were extracted and the same volume of extract was applied to each gel slot to compare samples on an equal-protein basis. This was done so that observed differences among patterns would be due to real compositional differences rather than to unequal protein application among the samples.

Albumins. The high-temperature drying affected the PAGE patterns of albumins (Fig. 2). There was an increase in intensity of low-mobility bands (region labeled A). Some bands in the high-mobility region increased while others decreased in intensity (regions labeled B and C). Also some bands of highest mobility became very faint as drying temperature increased, and these bands did not appear in the spaghetti dried at very high temperature.

SDS-PAGE patterns of albumins (not shown) showed that the intensity of certain bands became fainter as drying temperature increased, and very low intensity of some of these bands in the spaghetti dried at very high temperature was observed. SDS-PAGE patterns of albumins also showed that the intensity of lower-molecular-weight bands (molecular weight below 20,000) was not affected by high-temperature drying. In contrast, the PAGE patterns of albumins showed that the bands of highest mobility were affected by high-temperature drying.

Globulins. PAGE patterns of globulins are shown in Figure 3. The region labeled A shows opposite varietal effects, that is, bands decreased in intensity for Vic while they increased in intensity for Rugby as temperature increased. The high-temperature drying effect was similar to that observed for albumins for some high-mobility bands (labeled B in Fig. 3), that is, an increase in intensity of some bands and a decrease of others.

SDS-PAGE patterns of globulins (Fig. 4) showed that two bands of low mobility in the semolina sample in the 97,000 and 66,200 mol wt regions (arrows 1 and 2) seemed very susceptible to drying temperature since they almost disappeared in both varieties as drying temperature increased. Generally, the intensity of the bands in the region labeled A became much fainter in Vic than in Rugby, indicating that Vic proteins may be more susceptible to changes from high-temperature processing. Also the bands in the lowest molecular weight region (labeled B) showed that the 14,400 mol wt band decreased in intensity up to 80°C and then increased in intensity at 90°C for both varieties. The other bands in region B decreased in staining intensity as drying temperature increased.

Gliadins. The PAGE patterns of gliadins were affected only slightly by high-temperature drying (Fig. 5). It did not affect the low- and mid-mobility bands. A decrease in intensity of a few of the high-mobility bands (labeled A) was observed, especially in the variety Rugby. This decrease was more pronounced when

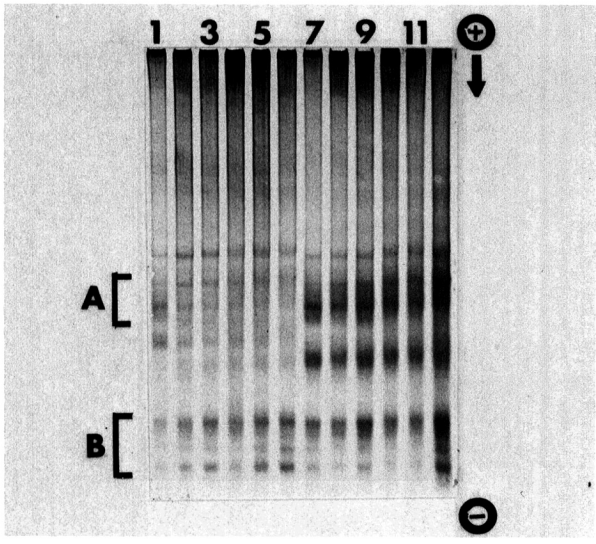

Fig. 3. Polyacrylamide gel electrophoresis patterns of globulin of Vic (patterns 1–6) and Rugby (patterns 7–12) samples: 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. A = intermediate-mobility bands, B = high-mobility bands.

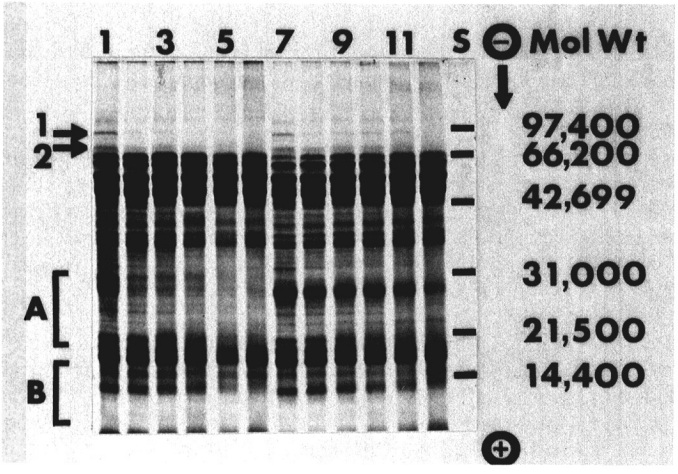

Fig. 4. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of globulin of Vic (patterns 1–6) and Rugby (patterns) 7–12) samples: S, molecular weight standards; 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. Arrows 1 and 2, A, and B = regions showing differing effects of increased drying temperature.

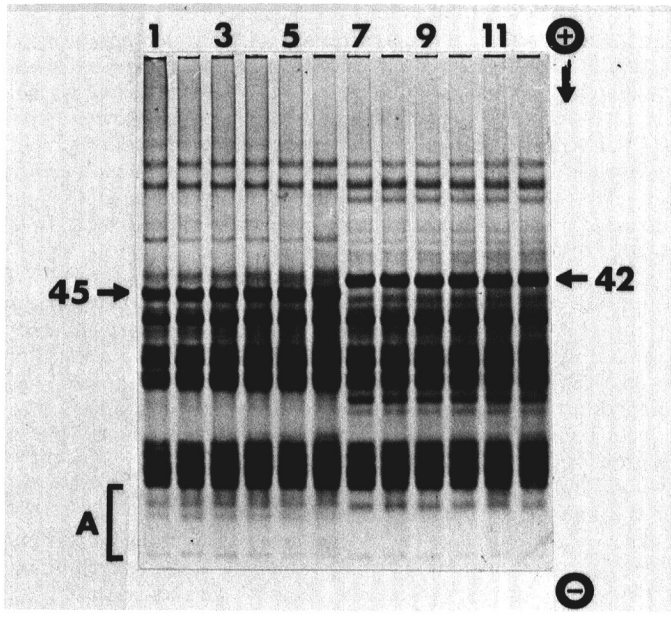

Fig. 5. Polyacrylamide gel electrophoresis patterns of gliadin of Vic (patterns 1–6) and Rugby (patterns 7–12) samples: 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. Vic contains band 45 and Rugby contains band 42; these are related to strong and weak gluten, respectively. A = high-mobility bands.

very-high-temperature drying was used (patterns 6 and 12).

The SDS-PAGE patterns of gliadins (not shown) showed that only very few bands became fainter as drying temperature increased. The results of this study agree with those of Pence et al (1953), who found that the gliadin fraction was the most stable to heat denaturation, as measured by acetic acid solubility (Table I). Schofield et al (1983), however, found that heating of wheat gluten above 70°C affected the gliadin proteins. It may be concluded that the gliadin fraction is essentially not affected by high-temperature drying of spaghetti. The absence of major changes in gliadins attributable to drying temperature is indirect evidence that this fraction is not of primary importance to drying temperature-induced effects on pasta cooking quality. On the other hand, the stability of gliadin to temperature effects may be important in maintaining the cooking quality of pasta products.

Glutenins. SDS-PAGE patterns of glutenins (Fig. 6) showed clear quantitative differences in band intensities of the dried spaghetti samples compared to those of the semolina samples. The intensity of some higher molecular weight (approximately 66,000–110,000 mol wt) glutenin bands (labeled A) decreased in intensity for both varieties as drying temperature increased. The intensity of the lower molecular weight (approximately less than 31,000 mol wt) bands (labeled B) became more brightly stained with high-temperature drying.

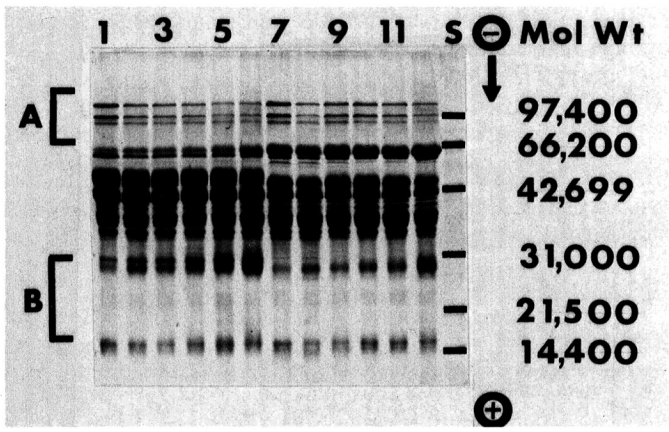

Fig. 6. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of glutenin of Vic (patterns 1–6) and Rugby (patterns 7–12) samples: S, molecular weight standards; 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. A and B = regions showing differing effects of increased drying temperature.

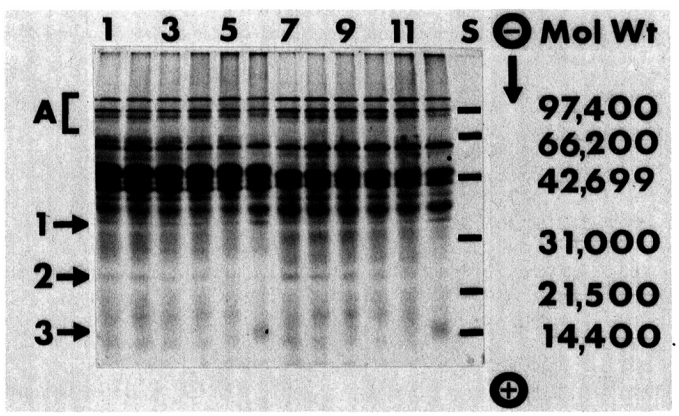

Fig. 7. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis patterns of residue of Vic (patterns 1–6) and Rugby (patterns 7–12) samples: S, molecular weight standards; 1 and 7, semolina; 2 and 8, 40°C-dried spaghetti; 3 and 9, 60°C-dried spaghetti; 4 and 10, 70°C-dried spaghetti; 5 and 11, 80°C-dried spaghetti; 6 and 12, 90°C-dried spaghetti. A and arrows 1–3 = regions showing differing effects of increased drying temperature.

The increase in intensity of the protein components in the lower molecular weight region and decrease in intensity in the higher molecular weight region agree with the results of Feillet et al (1989) (for 55°C-dried spaghetti) and Autran and Galterio (1989) (for low-temperature-dried spaghetti). Schofield et al (1983) also indicated that the glutenin fraction was affected predominantly by heating of wheat gluten. The low molecular weight glutenins were found, in general, to be good indicators of viscoelastic properties (Payne et al 1984). Payne et al (1984) also proposed that the low molecular weight glutenins were the casual agents of gluten strength in durum wheats and that gliadin bands 42 and 45 (Damidaux et al 1980) were simply quality markers.

Residue. SDS-PAGE patterns of residue proteins (Fig. 7) were similar to the SDS-PAGE patterns of glutenins; that is, quantitative differences in band intensities both in the high and the low molecular weight regions were observed upon high-temperature drying. In the high molecular weight region labeled A, the third band became less intense, whereas the first and second bands were essentially unaffected. The intensity of one band increased (arrow 1), whereas another band (arrow 2) disappeared

TABLE III
Effect of Drying Temperature on Retention Times of Peaks from Reversed-Phase High-Performance Liquid Chromatography Profiles of Spaghetti Samples of Vic Variety Durum Wheat

	Retention Time (mean)[a]			
		Drying Temperature of Spaghetti, °C		
Peak	Semolina	40	80	90
1	18.92 c	19.13 a	18.97 bc	18.82 d
2	19.55 cd	19.76 a	19.62 bc	19.48 d
3	20.26 b	20.40 a	20.22 b	20.07 c
4	22.20 b	22.31 a	22.11 b	21.96 c
5	22.83 b	22.96 a	22.75 b	22.62 c
6	23.65 b	23.75 a	23.55 c	23.40 c
7	24.24 ab	24.29 a	24.09 c	23.98 d
8	25.18 b	25.27 a	25.07 c	24.93 d
9	26.55 b	26.68 a	26.48 b	26.35 c
10	27.51 bc	27.66 a	27.39 d	27.27 e
11	28.58 ab	28.68 a	28.44 c	28.32 d
12	30.54 a–c	30.69 a	30.37 b–d	30.23 d
13	31.56 ab	31.59 a	31.36 c	31.26 c
14	32.35 a	32.37 a	32.15 bc	32.04 c
15	33.08 a	33.10 a	32.86 bc	32.77 c
16	33.87 a	33.90 a	33.68 bc	33.60 c
17	36.52 ab	36.59 a	36.36 cd	36.29 d
18	37.45 ab	37.53 a	37.22 cd	37.18 d
19	39.09 ab	39.19 a	38.88 c	38.82 c
20	41.14 ab	41.24 a	41.03 bc	40.94 c

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

TABLE IV
Effect of Drying Temperature on Peak Areas of Peaks from Reversed-Phase High-Performance Liquid Chromatography Profiles of Spaghetti Samples of Vic Variety Durum Wheat

	Peak Area (mean)[a]			
		Drying Temperature of Spaghetti, °C		
Peak	Semolina	40	80	90
2	0.85 b	0.98 b	0.89 b	1.35 a
3	2.73 b	3.04 ab	2.66 b	3.55 a
4	3.13 b	3.22 b	3.08 b	3.90 a
5	3.08 d	3.38 c	3.59 b	3.93 a
8	8.91 b	9.05 b	8.90 b	10.08 a
11	12.76 b	13.30 a	13.64 a	13.29 a
12	4.60 a	4.36 ab	3.37 bc	2.64 c
14	3.73 b	3.45 c	3.75 b	3.73 b
15	4.79 a	4.56 ab	4.19 c	3.77 d
16	11.71 a	11.41 a	11.77 a	10.16 b
18	13.48 a	11.51 bc	12.73 ab	10.94 c

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

at very-high-temperature drying conditions. Another band (arrow 3) became more intense at very-high-temperature (90°C) drying conditions (patterns 6 and 12).

RP-HPLC

RP-HPLC of the gliadin fraction of spaghetti samples dried at high temperature clearly demonstrates quantitative differences among samples. Duncan's multiple range test for retention times (Table III) for Vic variety showed that many peaks, affected significantly by high-temperature drying, appeared to shift to shorter retention times. Other peaks (not shown in the table) remained relatively constant. RP-HPLC peaks from spaghetti dried at low temperature (40°C) always gave longer retention times, whereas those from spaghetti dried at very high temperature (90°C) gave shorter retention times for every peak. Also, no large significant differences were found in retention time values among the spaghetti samples dried at 60, 70 and 80°C.

Duncan's multiple range test showed that the peak areas of the variety Vic were affected by high-temperature drying (Table IV). The values of peak areas generally remained constant for semolina and spaghetti dried up to 80°C. However, at 90°C the values of peak area generally increased in early-eluted peaks (2–5, 8, and 11) and decreased in late-eluted peaks (12, 14–16, and 18).

Table V shows the Duncan's multiple range test for retention times for the variety Rugby. Drying temperature had a significant effect on retention times of some peaks (only those peaks that show significant differences are reported in Table V). Peaks from semolina samples gave the highest retention times, and they differed significantly from the retention times of spaghetti dried at the various temperatures. Generally, the retention times of peaks of the spaghetti dried at 40–80°C did not show significant differences. Duncan's multiple range test (Table VI) showed that drying temperature had very little effect on peak areas in the variety Rugby. Only two peaks showed a significant increase in peak areas. Since surface hydrophobicity is related to protein structures, conformations and functionality, RP-HPLC may be able to reveal damaged or denatured proteins. Schofield et al (1983) indicated that gluten "vitality" can be lost upon high-temperature drying.

TABLE V
Effect of Drying Temperature on Retention Times of Peaks from Reversed-Phase High-Performance Liquid Chromatography Profiles of Spaghetti Samples of Rugby Variety Durum Wheat

	Retention Time (mean)[a]			
		Drying Temperature of Spaghetti, °C		
Peak	Semolina	40	80	90
1	18.64 a	18.55 b	18.51 b	18.52 b
2	19.29 a	19.20 b	19.16 b	19.17 b
3	20.04 a	19.98 ab	19.88 bc	19.87 c
4	20.65 a	20.58 bc	20.53 cd	20.52 d
5	21.89 a	21.84 ab	21.72 c	21.72 c
6	22.57 a	22.49 ab	22.38 cd	22.37 d
7	23.35 a	23.28 ab	23.18 b	23.18 b
8	23.92 a	23.89 ab	23.77 cd	23.73 d
9	24.88 a	24.86 a	24.74 bc	24.73 c
14	31.98 a	31.95 ab	31.82 c	31.84 c
15	33.04 a	33.04 a	32.92 b	32.95 b

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

TABLE VI
Effect of Drying Temperature on Peak Areas of Peaks from Reversed-Phase High-Performance Liquid Chromatography Profiles of Spaghetti Samples of Rugby Variety Durum Wheat

	Peak Area (mean)[a]			
		Drying Temperature of Spaghetti, °C		
Peak	Semolina	40	80	90
2	0.97 b	0.97 b	0.84 c	1.02 a
16	6.72 c	7.45 b	7.52 b	7.92 a

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

CONCLUSIONS

The results of this study showed that high-temperature drying of spaghetti did not adversely affect spaghetti quality factors but rather enhanced color and firmness and reduced cooking losses. However, high-temperature drying changed the properties of the proteins, as indicated by protein solubility fractionation, PAGE, SDS-PAGE, and RP-HPLC data. Even though the solubility of the gliadin fraction was reduced as drying temperature increased, the relative composition of its proteins was minimally affected. However, the RP-HPLC data showed that high-temperature drying of spaghetti affected the retention times and peak areas of the gliadin proteins. The gliadins of the strong gluten variety Vic showed more susceptibility to high-temperature drying than did those of the weaker gluten variety Rugby, indicating greater sensitivity to temperature differences in the surface hydrophobic properties of Vic gliadins than in those of the weak gluten variety Rugby. As indicated by the cooking quality data, these changes in protein properties did not adversely affect technological properties but enhanced them. Since the high molecular weight subunits of glutenin were affected by high-temperature drying of spaghetti, it may be possible to detect pasta products processed by high temperature by analysis of the high molecular weight subunits by SDS-PAGE.

ACKNOWLEDGMENT

The Turkish Government through the FAO provided financial support to B. Aktan. The Northern Crops Institute, Fargo, ND, provided assistance in pasta processing.

LITERATURE CITED

AKTAN, B. 1990. The effects of high temperature and very high temperature drying of pasta on quality and biochemical constituents. M.S. thesis, North Dakota State University: Fargo.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 46–11, approved October 1976, revised October 1982; Method 46-13, approved October 1976, reviewed October 1982. The Association: St. Paul, MN.

AUTRAN, J. C., and GALTERIO, G. 1989. Associations between electrophoresis composition of proteins, quality characteristics and agronomic attributes of durum wheats. II. Protein-quality associations J. Cereal Sci. 9:195.

BANASIK, O. J. 1981. Pasta processing. Cereal Foods World 26:166.

BARONI, D. 1988. Manufacture of pasta products. Page 191 in: Durum Wheat: Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

BERGLUND, P. T., DICK, J. W., and DREHER, M. L. 1987. Effect of form of enrichment and iron on thiamine, riboflavin and niacinamide and cooking parameters of enriched spaghetti. J. Food Sci. 52:1367.

BRAIBANTI, C.S.P.A. 1980. New developments in pasta drying technology. Macaroni J. 61:48.

BUHLER-MIAG, INC. 1979. "High temperature" drying of pasta product. Macaroni J. 60:30.

CHEN, C. H., and BUSHUK, W. 1970. Nature of proteins in Triticale and its species. I. Solubility characteristics and amino acid composition of endosperm protein. Can. J. Plant Sci. 50:9.

CUBADDA, R., and RESMINI, P. 1968. Applicazione del metodo elettroforetico nella ricerca del frumento tenero in paste alimentari essiccate a varie temperature. Quad. Nutr. 28:81.

DAMIDAUX, R., AUTRAN, J. C., and FEILLET, P. 1980. Gliadin electrophoregrams and measurements of gluten viscoelasticity in durum wheats. Cereal Foods World 25:754.

DEXTER, J. E., and MATSUO, R. R. 1977. Changes in semolina proteins during spaghetti processing. Cereal Chem. 54:882.

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

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

cooking quality characteristics. J. Food Sci. 48:1545.
DEXTER, J. E., KILBORN, R. H., MORGAN, B. C., and MATSUO, R. R. 1983b. Grain Research Laboratory compression tester: Instrumental measurements of cooked spaghetti stickiness. Cereal Chem. 60:139.
DEXTER, J. E., TKACHUK, R., and MATSUO, R. R. 1984. Amino acid composition of spaghetti: Effect of drying conditions on total and available lysine. J. Food Sci. 49:225.
DICK, J. W., WALSH, D. E., and GILLES, K. A. 1974. The effect of field sprouting on the quality of durum wheat. Cereal Chem. 51:180.
FEILLET, P. 1988. Protein and enzyme composition of durum wheat. Page 93 in: Durum Wheat: Chemistry and Technology. G. Fabriani and C. Lintas, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.
FEILLET, P., AIT-MOUH, O., KOBREHEL, K., and AUTRAN, J. C. 1989. The role of low molecular weight glutenin proteins in the determination of cooking quality of pasta products: An overview. Cereal Chem. 66:26.
GILLES, K. A., SIBBITT, L. D., and SHUEY, W. C. 1966. Automatic laboratory dryer for macaroni products. Cereal Sci. Today 11:322.
HOSKINS, C. M., and HOSKINS, G. G. 1959. A window on methods and problems in today's macaroni industry. Cereal Sci. Today 4:31.
HUEBNER, F. R., and BIETZ, J. A. 1987. Improvements in wheat protein analysis and quality prediction by reversed-phase high-performance liquid chromatography. Cereal Chem. 64:15.
IBRAHIM, R. H. R. 1982. High temperature drying of pasta. Ph.D. thesis, North Dakota State University: Fargo.
KHAN, K., HAMADA, A. S., and PATEK, J. 1985. Polyacrylamide gel electrophoresis for wheat variety identification: Effect of variables on gel properties. Cereal Chem. 62:310.
KHAN, K., JACOBSEN, A., and HUCKLE, L. 1988. Improvements in Polyacrylamide Gel Electrophoresis of Gliadin Proteins for Wheat Variety Identification: Effect of Gel Dimensions, Apparatus Design, Buffer Systems and Other Variables on Resolution and Separation. Manual. Dept. of Cereal Science and Food Technology, North Dakota State University: Fargo.
KIM, S. H. 1981. Extrusion cooking of durum semolina. M.S. thesis, North Dakota State University: Fargo.
KOBREHEL, K., and ABECASSIS, J. 1985. Effect of high temperature drying of pasta products on the composition and activity of peroxidases in relationship with the color of spaghetti. Lebensm. Wiss. Technol. 18:277.
LAEMMLI, U. K. 1970. Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227:680.
MANSER, J. 1980. High-temperature drying of pasta products. Buhler Diag. 69:11.
MOK, C. 1988. Moisture sorption and cracking of spaghetti. Ph.D. thesis, North Dakota State University: Fargo.
PAGANI, M. A., RESMINI, P., FIORINO, A., and DALBON, G. 1986. High temperature drying in egg pasta-making: Effects on some organoleptic and nutritional characteristics. Tec. Molitoria 37(3):177.
PAVAN, G. 1979. High temperature drying of pasta products. Lebensmittelindustrie 26:319.
PAVAN, G. 1980. High temperature drying improves pasta quality. Food Eng. Int. 5:37.
PAYNE, P. I., JACKSON, E. A., and HOLT, L. M. 1984. The association between gamma-gliadin 45 and gluten strength in durum wheat varieties: A direct causal effect or the result of genetic linkage? J. Cereal Sci. 2:73.
PENCE, J. W., MOHAMMAD, A., and MECHAM, D. K. 1953. Heat denaturation of gluten. Cereal Chem. 30:115.
RESMINI, P., and PAGANI, M. A. 1983. Ultrastructure studies of pasta. A Review. Food Microstruct. 2:1.
SAS Institute. 1986. SAS User's Guide: Statistics. The Institute: Cary, NC.
SCHOFIELD, J. D., BOTTOMLEY, R. C., TIMMS, M. F., and BOOTH, M. R. 1983. The effect of heat on wheat gluten and the involvement of sulphydryl-disulphide interchange reactions. J. Cereal Sci. 1:241.
SEYAM, A., SHUEY, W. C., MANEVAL, R. D., and WALSH, D. E. 1974. Effect of particle size on processing and quality of pasta products. Assoc. Oper. Millers Tech. Bull. December, p. 3497.
WALSH, D. E. 1970. Measurement of spaghetti color. Macaroni J. 52:20.
WALSH, D. E. 1971. Measuring spaghetti firmness. Cereal Sci. Today 16:202.
WASIK, R. J. 1978. Relationship of protein composition of durum wheat with pasta quality and the effects of processing and cooking on these proteins. Can. Inst. Food Sci. Technol. J. 11:129.
WYLAND, A. R., and D'APPOLONIA, B. L. 1982. Influence of drying temperature and farina blending on spaghetti quality. Cereal Chem. 59:199.

[Received June 13, 1991. Revision received December 27, 1991. Accepted January 6, 1992.]