Textural Optimization of Spaghetti Using Response Surface Methodology: Effects of Drying Temperature and Durum Protein Level[1]

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ABSTRACT

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The effects of durum protein level and spaghetti drying temperature on cooked spaghetti quality were investigated using response surface methodology. Five drying temperatures (40, 60, 70, 80, and 90°C) and seven durum semolina protein levels (11-17%) were examined. Firmness and compressibility of both optimally cooked and overcooked spaghetti were primarily affected by protein level, whereas elasticity was mainly affected by drying temperature. Cooking loss of optimally cooked spaghetti was primarily influenced by protein level, whereas cooking loss of overcooked spaghetti was influenced by both variables. To produce spaghetti of comparable commercial quality, drying temperatures greater than 60°C were required for low-protein semolina. At protein levels greater than 14%, satisfactory spaghetti quality could be produced using a drying temperature of 50°C.

The basis of a good cooking-quality durum wheat is one in which the protein forms an insoluble network entrapping swollen and gelatinized starch granules (Feillet 1984). This prevents spaghetti surface disruption and consequent leaching of carbohydrates and proteins into the cooking water. Both protein quantity and quality are important factors influencing pasta cooking quality.

Matveef (1966) has shown that a durum wheat protein content above 13% yields a satisfactory final product, whereas a protein content lower than 11% gave a poor product. Spaghetti cooking quality improves as protein content increases (Matsuo et al 1972, Dexter and Matsuo 1977, Grzybowski and Donnelly 1979, Autran et al 1986). Protein quality, measured by gluten properties, also influences the cooking quality of spaghetti (Matveef 1966, Sheu et al 1967, Matsuo and Irvine 1970, Matsuo et al 1972, Dexter and Matsuo 1977, Grzybowski and Donnelly 1979). Feillet et al (1977) demonstrated that strong gluten varieties with high elastic recovery exhibit good cooking quality, while weak gluten varieties with low elastic recovery have poorer quality.

Recent innovations in pasta-drying technology resulted in the use of high-temperature (HT) and very high-temperature (VHT) drying lines. HT drying refers to temperatures between 60 and 90°C (Manser 1980); VHT drying refers to temperatures greater than 90°C. Low temperature (LT) or conventional drying refers to the use of temperatures no higher than 60°C (Dalbon and Oehler 1983). Reported benefits of HT/VHT drying include: reduced drying times, improved microbiological quality, and enhanced cooking quality. According to Manser (1980), pasta dried under HT are firmer and less sticky.

HT can be applied at the start of the drying cycle or after LT predrying. The first method has not proven effective in enhancing pasta cooking quality (Dexter et al 1981a, Taha and Sagi 1988). Manser (1980) speculated that the poorer cooking quality of spaghetti dried initially at HT may be due to premature denaturation of gluten and, possibly, some starch gelatinization. The second method appears to yield pasta with improved cooking quality (Manser 1980; Dexter et al 1981b, 1984; Wyland and D'Appolonia 1982). Resmini and Pagani (1983) and Abecassis et al (1989a,b) reported that the best cooking quality is achieved with a drying cycle that applies HT after first achieving a low moisture content using LT drying conditions.

The ability to produce pasta with good cooking quality using HT drying has caused a number of workers to question the need for using high-quality raw materials in the production of pasta. That is, it may be possible to use lower protein durum wheat to produce pasta with good cooking quality. Studies by Dexter et al (1981b, 1983) provide some evidence to support this suggestion. The cooking losses of low-protein semolina were greatly reduced with HT drying (Dexter et al 1981b), although this was less obvious in a later study (Dexter et al 1983). Examination of stickiness data revealed that only one of two varieties of durum tested (at both a high- and low-protein content) had improved surface characteristics when processed at HT. The other variety showed no improvement at either protein level when processed at HT. Furthermore, recovery improved only at HT for the higher protein samples, and firmness actually decreased for the low-protein samples processed at HT. Clearly, more work needs to be done to assess the relationship of spaghetti-drying temperature and semolina protein level on the cooking quality of spaghetti. It would be of great interest to determine which combinations of drying temperatures and protein levels yield optimum spaghetti. Thus, the objective of this study was to examine the effects of spaghetti-drying temperature and durum semolina protein levels on cooked spaghetti quality characteristics.

MATERIALS AND METHODS

Selection and Analysis of Plant Material

Harvest survey samples of durum wheat from the 1988 crop, qualifying for no. 1 Canadian Western Amber Durum (CWAD) grade, were screened initially for protein content using near-infrared reflectance (NIR) spectroscopy (Automated Digital Analyzer, Neotec, Silver Springs, MD). Based on these findings, samples were segregated into seven protein levels ranging from 12 to 18%. The composite samples were then analyzed for protein content by the standard Kjeldahl method, as modified by Williams (1973), for confirmation. To ensure composite samples had similar varietal composition, 100 kernels of each sample were examined by acidic polyacrylamide gel electrophoresis following the method of Tkachuk and Mellish (1980).

Ash content of wheat samples was determined by placing 4-g samples in silica dishes and incinerating overnight at 600°C. After cooling, the dishes and ash were weighed, the ash brushed out, the dishes reweighed, and the weight of ash determined by difference.

Alpha-amylase levels in the wheat were examined to determine the presence of sprout damage. High amylolytic activity in spaghetti can increase the amount of residue in the cooking water, increase the level of reducing sugars in both semolina and spaghetti, and has a tendency to give a slightly softer cooked spaghetti (Matsuo et al 1982b). Levels were determined using the method of Kruger and Tipples (1981).

Gluten strength was estimated by the sodium dodecyl sulfate (SDS) sedimentation test as described by Axford et al (1979), except that a 3% solution of SDS was used.

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Determinations of protein, ash, alpha-amylase, and SDS sedimentation values were performed in duplicate on the seven wheat samples.

Milling and Assessment of Semolina Quality

Wheat samples were cleaned, scoured, and tempered overnight to 16.5% moisture. The mill room was controlled for temperature (22°C) and humidity (rh 60%). Samples were milled using a modified Allis-Chalmers procedure as described by Matsuo and Dexter (1980). Semolina yields of 65% were obtained.

Semolina protein and ash content were determined in duplicate as previously described. Wet gluten content of semolina samples was determined in duplicate using the Glutomatic system according to ICC Standard Method 137 (ICC 1982).

Spaghetti Processing and Drying

Spaghetti was processed by the micro spaghetti-making procedure of Matsuo et al (1972). Samples were dried using five temperature conditions (40, 60, 70, 80, and 90°C) modeled after commercial drying cycles. A modified Blue M FR-381C environment chamber (Blue M Electric Co., Blue Island, IL), as described by Dexter et al (1981b), was used for drying the spaghetti.

Assessment of Cooked Spaghetti Quality

Spaghetti samples were cooked to optimum (point when the center core disappears) and to optimum plus 10 min (a measurement of tolerance to overcooking) in prepared water as described by Malcolmson and Matsuo (1992).

Predicted cooking loss values were determined from iodine absorbance values measured at 650 nm following the method developed by Matsuo et al (1992). Absorbance values were determined in duplicate for a total of four determinations.

Firmness, compressibility, elasticity, and strand stickiness were measured using an Instron tester (Model 4201 equipped with an ion-compression load cell) following the procedures described by Malcolmson (1991), except SI units of measurement were used. Thus, a compression force of 8 N was used for compression and relaxation studies, and a compression force of 0.5 N was used for studies on strand stickiness. Duplicate measurements of two subsamples per replicate were completed for firmness, compression, and relaxation for a total of eight determinations. Duplicate measurements per replicate were completed for strand stickiness for a total of four determinations.

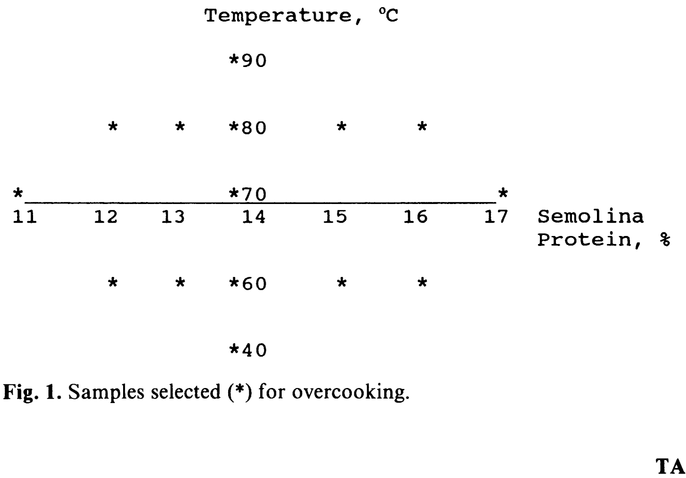

Fig. 1. Samples selected (*) for overcooking.

Experimental Design and Statistical Analysis of Data

Thirty-five treatment combinations (seven protein levels × five drying temperatures) were processed and evaluated in each of two processing replicates for a total of 70 samples. Because this was an excessive number of samples to cook, only 15 treatment combinations were submitted to overcooking, using the selection procedure outlined in Figure 1. Thus, 70 samples were cooked to optimum and 30 were overcooked.

Data were analyzed using the RSREG procedure of the Statistical Analysis System (SAS 1988) to fit second-order polynomial equations to all response variables. Lack-of-fit tests were performed on the fitted models. Coefficients for the linear, quadratic, and interaction terms of each polynomial were calculated and tested for difference from zero. Response surface two-dimensional contour plots were generated from the fitted models using the GCONTOUR procedure (SAS 1988).

RESULTS AND DISCUSSION

Wheat and Semolina Characteristics

Wheat and semolina characteristics are provided in Table I. Wheat protein levels ranged from 11.8 to 18.3%, with semolina protein levels ranging from 10.7 to 17.3%. According to Irvine (1971), semolina with protein levels of 11.5–13.0% process with little difficulty and can be expected to give satisfactory results. Lower protein semolinas can produce pasta with poor mechanical strength in the dried product, lower cooking stability, and less cooked firmness (Grzybowski and Donnelly 1979). Too high a protein level may result in pasta that stretches excessively upon extrusion (Irvine 1971).

Ash levels for wheat ranged from 1.52 to 1.8% and for semolina from 0.62 to 0.78% (Table I). Ash levels in commercial durum semolina (of about 65% extraction rate) generally range from 0.55 to 0.75% (14% mb) (Irvine 1971). Thus, the ash levels of the semolina samples used in this study were similar to ash levels in commercial durum semolina.

Alpha-amylase levels ranged from 1.9 to 11.9 mg of malt per min/g × 10^{-3}, indicating low amylolytic activity. The levels exhibited normal variation and were not considered a factor in the differences in cooking quality observed between the samples.

Not surprisingly, SDS sedimentation values (a measure of wheat gluten strength) and wet gluten content increased with increasing protein levels. Thus, as protein level increased, gluten strength increased, and higher levels of gluten were found. Gluten properties have been identified as an essential factor of cooking quality (Matveef 1966, Sheu et al 1967, Matsuo and Irvine 1970). Dexter and Matsuo (1977) reported that gluten characteristics improved with increasing protein content. Matsuo et al (1982a) were unable to confirm that protein content significantly affected gluten quality. Similarly, Autran et al (1986) found gluten characteristics

TABLE I
Wheat and Semolina Quality Characteristics of Composite Samples

Quality Parameter	Wheat Protein Level Designation, % 12	13	14	15	16	17	18
Wheat							
Protein, %[a]	11.80	13.20	14.30	15.10	16.50	17.00	18.30
Ash, %	1.58	1.56	1.55	1.52	1.63	1.67	1.80
Sodium dodecyl sulfate sedimentation, ml	33.50	37.00	40.50	42.50	43.00	42.50	44.50
α-Amylase ([mg of malt per min/g] × 10^{-3})	1.90	2.60	4.30	4.80	3.60	5.70	11.90
Semolina							
Protein, %[b]	10.70	12.10	13.00	13.70	14.90	16.20	17.30
Ash, %	0.64	0.66	0.65	0.62	0.64	0.72	0.78
Wet gluten, %[b]	31.20	33.30	36.60	39.50	41.40	45.70	48.50

[a] 13.5% moisture basis, N × 5.7.
[b] 14.0% moisture basis.

were independent of protein content. Results of our study show a strong relationship between protein content and gluten characteristics as measured by SDS sedimentation and wet gluten content.

Varietal composition of the seven composite samples is provided in Table II. One of our concerns was the proportion of Wascana variety in the composite because Wascana contains gliadin band 42, which is associated with weak gluten. However, the observed range of 11–19% was not considered large enough to influence our results. All other varieties contained gliadin band 45, which is associated with strong gluten. Thus, we felt that the observed differences in varietal composition were not a factor in our results.

Drying Cycles

Drying temperature, humidity conditions, and spaghetti moisture profiles for each of the five drying cycles are provided in Figure 2. Compared to the conventional low-temperature (40°C) drying cycle (Fig. 2A), all of the HT cycles (Fig. 2B–E) resulted in more rapid loss of moisture from the spaghetti during the earlier stages of drying. The moisture content of the spaghetti at the end of each cycle was about 12%, but upon equilibration at room conditions, moisture decreased to about 9%.

In the 40°C drying cycle (Fig. 2A), spaghetti was dried over a 16-hr period with a controlled decrease in relative humidity. Temperature was maintained at 40°C for the entire 16-hr period before equilibration to room conditions. The 60 and 70°C cycles (Fig. 2B and C) featured an initial 10-hr exposure to the high temperature, followed by a decrease in the temperature to 40°C and 6-hr holding before equilibration to room conditions. The 80 and 90°C cycles (Fig. 2D and E) featured a short initial exposure to the high temperature, followed by a decrease in temperature to 70°C and holding for several hours. This was followed by a decrease in temperature to 40°C and stabilization.

Response Surface Analysis

To gain a better understanding of the relationship between protein level and drying temperature and their effects on cooked spaghetti quality, response surface methodology (RSM) was applied to the data collected.

The analysis of variance for the two predictor variables (drying temperature and protein level) of the quality parameters measured on optimally cooked and overcooked spaghetti are presented in Tables III and IV, respectively. Several criteria can be used to evaluate the adequacy of the fitted model. A test for lack-of-fit can be used wherein a low F value indicates that the second-order model is an adequate approximation to the data (Morgan et al 1989). Joglekar and May (1987) suggest that R^2 values, *CV* values, and model significance be used to judge the adequacy of the model. R^2 is the proportion of variation in the response attributed to the model rather than to random error (Khuri and Cornell 1987). *CV* describes the amount of variation in a population relative to the mean. Model significance indicates the level of confidence that the selected model cannot be due to experimental error. Thus, according to Joglekar and May, for

TABLE II
Varietal Identification[a] of Wheat Composite Samples[b]

Variety	Wheat Protein Level Designation, %						
	12	13	14	15	16	17	18
Wascana	11	17	19	16	11	18	15
Wakooma A or Kyle[c]	37	39	34	13	36	48	43
Wakooma B	16	15	6	32	10	10	40
Medora	26	19	24	31	35	18	1
Macoun	...	2	...	2	...	...	...
Pelissier	1	2	8	3	6	1	...
Arcola	...	4	3	...	...	...	...
Coulter	9	2	6	3	1	5	...
Nondurum	...	...	...	...	1	...	...

[a] Based on electrophoretic analysis of 100 kernels.
[b] Proportion of variety, %.
[c] Indistinguishable by electrophoresis.

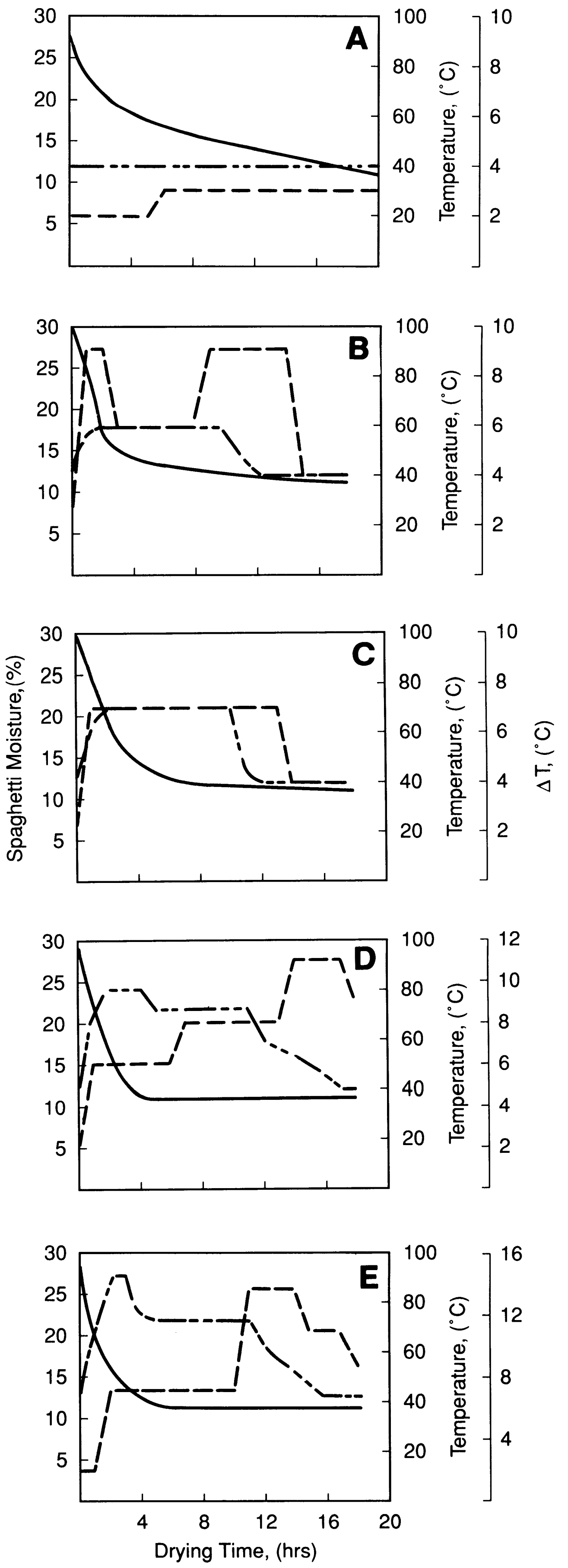

Fig. 2. Drying cycle (— - - —), dryer temperature (- - -), and humidity condition (——) for each of the five drying cycles. **A,** 40°C. **B,** 60°C. **C,** 70°C. **D,** 80°C. **E,** 90°C.

good fit of a model, R^2 should be at least 80%, *CV* should not exceed 10%, and model significance should be at least $P < 0.05$. An R^2 value of 80% appeared to be excessive for a preliminary study of this nature, so 60% was used.

The models developed for firmness, compression and cooking loss for optimally cooked and overcooked spaghetti, and relaxation time for overcooked spaghetti were considered highly adequate because they possessed no significant lack-of-fit and had satisfactory levels of R^2, *CV*, and model significance (Tables III and IV).

The predictive model for relaxation time of optimally cooked spaghetti was less predictive because the *CV* value was slightly higher than 10% and showed a significant lack-of-fit (Table III). Satisfactory levels of model significance and R^2 were obtained for this parameter, suggesting that the predictive model merits examination.

Models developed for strand stickiness were judged to be inadequate due to very low R^2 values; high *CV* values suggested high variability rather than model inadequacy because lack-of-fit tests were not significant. Test procedures, or high variation among the spaghetti strands themselves, could account for much of this variability.

To visualize the combined effects of the two predictor variables on the dependent responses of quality, two-dimensional contour plots were generated for each of the fitted models.

The contour plot for firmness of optimally cooked spaghetti is presented in Figure 3A. Spaghetti firmness increased with increasing semolina protein level and, to a modest extent, with higher drying temperatures. The area of optimized response (high firmness values) was defined by high levels of protein and high drying temperatures. Similar findings were observed for spaghetti that was overcooked (Fig. 3B).

Results for compression energy agreed with findings for firmness (Fig. 4). Lower compression values (indicating superior cooking quality) were achieved with higher protein levels and, to a lesser extent, with higher drying temperatures for both optimally cooked and overcooked spaghetti.

The contour plot for relaxation time of optimally cooked and overcooked spaghetti are presented in Figure 5. For both cooking times, a more pronounced change in the surface contour was observed along the drying-temperature axis than along the protein-level axis. Relaxation time increased with higher drying temperatures. The area of maximum response for both cooking times is defined by the highest drying temperatures and, to a lesser extent, by the higher protein levels.

Contour plots for cooking-loss values for optimally cooked spaghetti showed that cooking loss was less sensitive to changes in drying temperature than to changes in protein level (Fig. 6A). The area of optimum response for cooking loss was defined by the highest protein level. Contour plots for overcooked spaghetti (Fig. 6B) showed that cooking loss decreased in the direction of high drying temperatures and high protein levels. The region of optimum response was defined by the highest drying temperature and protein levels greater than 15%.

Cooking-quality values for a representative subsample of commercial durum spaghetti samples are presented in Table V. Experimental spaghetti samples generally met or exceeded these values. The only exceptions were for relaxation time of both optimally cooked and overcooked spaghetti and for cooking loss of overcooked spaghetti. For these parameters, in order to achieve

TABLE III

ANOVA[a] of Models for Optimally Cooked Spaghetti

Variable and Source	df	Sum of Squares	*F* Value	*P* Value
Firmness (shear force)				
Model	5	84.749	42.977	0.000
Residual	64	25.241		
Lack-of-fit	29	10.536	0.865	0.653
Pure error	35	14.705		
$R^2 = 0.77$				
Coefficient of variation (%) = 8.3				
Compression energy				
Model	5	2.973	36.390	0.000
Residual	64	1.046		
Lack-of-fit	29	0.523	1.205	0.297
Pure error	35	0.523		
$R^2 = 0.74$				
Coefficient of variation (%) = 5.9				
Relaxation time				
Model	5	2,774.937	21.481	0.000
Residual	64	1,653.553		
Lack-of-fit	29	1,213.538	3.329	0.000
Pure error	35	440.016		
$R^2 = 0.63$				
Coefficient of variation (%) = 15.2				
Strand stickiness				
Model	5	455,031.0	5.240	0.000
Residual	64	1,111,496.0		
Lack-of-fit	29	445,846.0	0.808	0.719
Pure error	35	665,650.0		
$R^2 = 0.29$				
Coefficient of variation (%) = 17.1				
Predicted cooking loss				
Model	5	11.454	30.034	0.000
Residual	64	4.882		
Lack-of-fit	29	2.909	1.780	0.052
Pure error	35	1.973		
$R^2 = 0.70$				
Coefficient of variation (%) = 4.9				

[a] Analysis of variance.

TABLE IV

ANOVA[a] of Models for Overcooked Spaghetti

Variable and Source	df	Sum of Squares	*F* Value	*P* Value
Firmness (shear force)				
Model	5	8.430	18.363	0.000
Residual	24	2.204		
Lack-of-fit	9	0.280	0.243	0.981
Pure error	15	1.924		
$R^2 = 0.79$				
Coefficient of variation (%) = 5.4				
Compression energy				
Model	5	0.600	16.489	0.000
Residual	24	0.175		
Lack-of-fit	9	0.021	0.230	0.984
Pure error	15	0.153		
$R^2 = 0.78$				
Coefficient of variation (%) = 2.9				
Relaxation time				
Model	5	575.616	15.770	0.000
Residual	24	175.209		
Lack-of-fit	9	100.115	2.222	0.083
Pure error	15	75.094		
$R^2 = 0.77$				
Coefficient of variation (%) = 10.7				
Strand stickiness				
Model	5	427,099.0	1.848	0.141
Residual	24	1,109,331.0		
Lack-of-fit	9	434,381.0	1.073	0.434
Pure error	15	674,950.0		
$R^2 = 0.28$				
Coefficient of variation (%) = 22.5				
Predicted cooking loss				
Model	5	11.944	23.287	0.000
Residual	24	2.462		
Lack-of-fit	9	1.306	1.883	0.134
Pure error	15	1.156		
$R^2 = 0.83$				
Coefficient of variation (%) = 4.5				

[a] Analysis of variance.

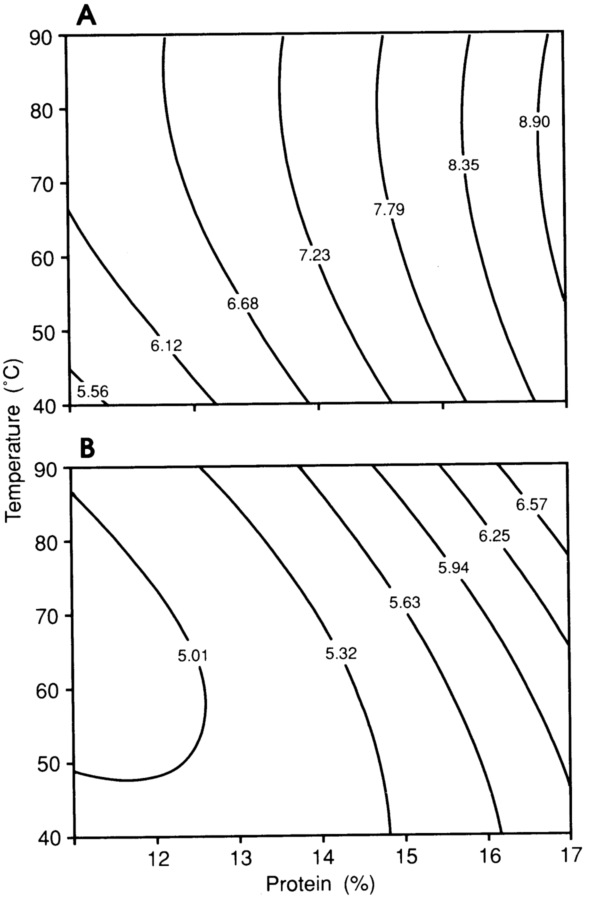

Fig. 3. Contour plots for spaghetti firmness. **A**, optimally cooked. **B**, overcooked.

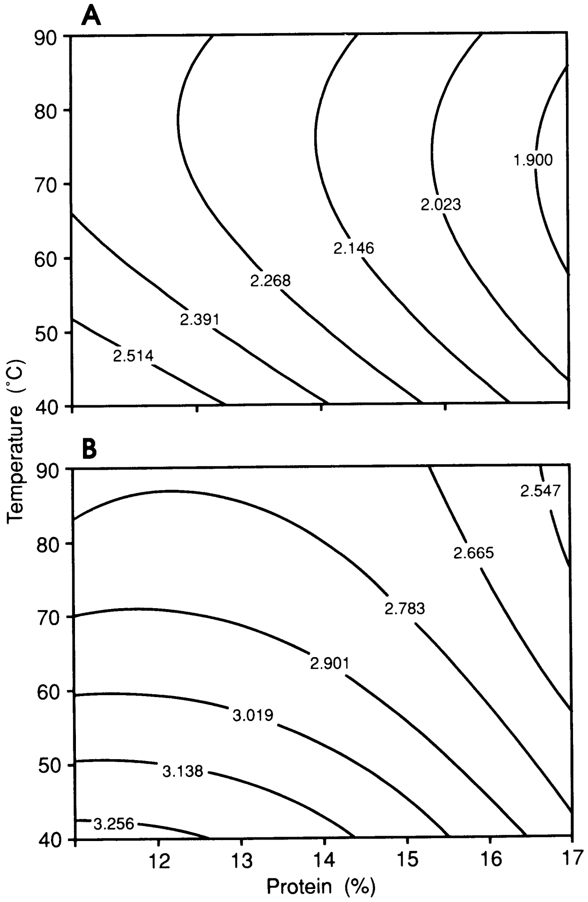

Fig. 4. Contour plots for spaghetti compression energy. **A**, optimally cooked. **B**, overcooked.

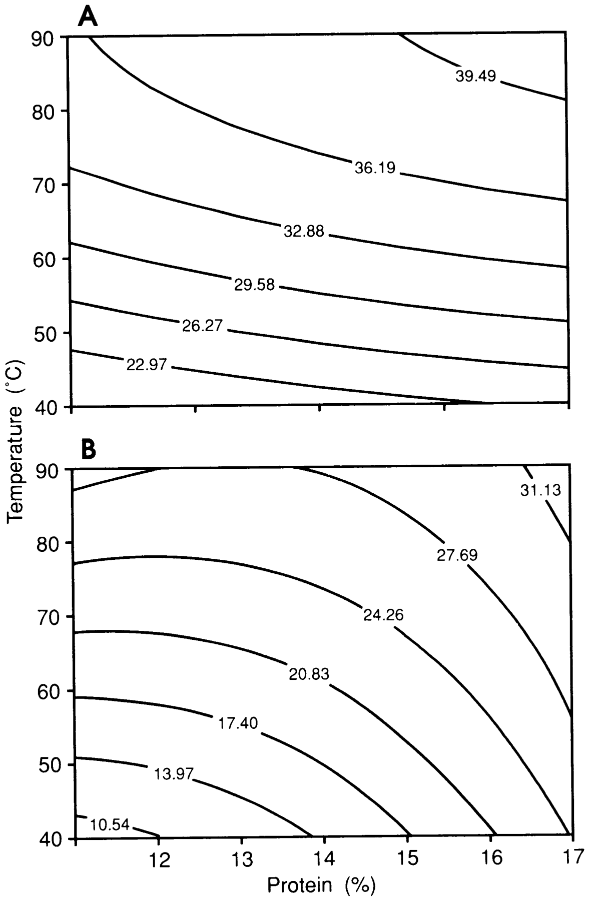

Fig. 5. Contour plots for spaghetti relaxation time. **A**, optimally cooked. **B**, overcooked.

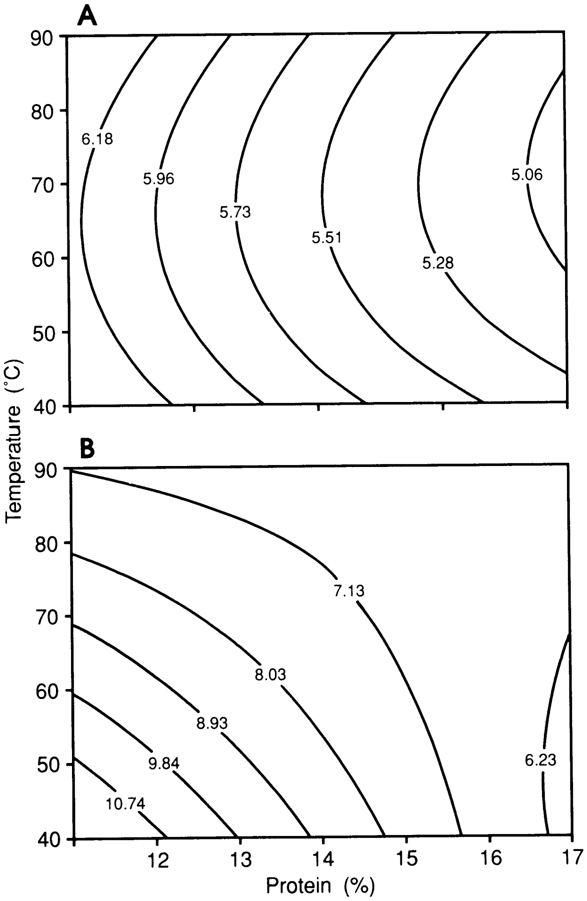

Fig. 6. Contour plots for spaghetti cooking loss. **A**, optimally cooked. **B**, overcooked.

spaghetti of comparable commercial quality at a protein level of 11%, a drying temperature greater than 60°C was required. At protein levels between 12 and 13%, a drying temperature of at least 55°C was required, whereas, at protein levels greater than 14%, drying temperatures greater than 50°C were needed. For higher durum protein levels, high drying temperatures were not as critical to the final quality of the cooked spaghetti.

Thus, this study confirmed that spaghetti cooking quality, as measured by Instron firmness, compression energy, relaxation time, and predicted cooking loss, improved as protein levels increased. Matveef (1966) reported that wheat protein levels above 13% gave satisfactory pasta, while protein levels lower than 11% resulted in poor pasta. The lowest wheat protein level used in this study was 12%. Numerous researchers (Matsuo et al 1972, Dexter and Matsuo 1977, Grzybowski and Donnelly 1979, Autran et al 1986) have shown that spaghetti firmness, elasticity, and surface characteristics improve with increasing protein content. This has been attributed to the higher number of polypeptide chains associated with higher protein levels that increase the chance for proteins to interact to form an insoluble network (Feillet 1984).

In this study, drying temperatures greater than 40°C significantly improved spaghetti cooking quality. Drying temperatures greater than 60°C did not appear to greatly improve spaghetti cooking quality for the drying cycles used in this study. Similar findings have been reported by other researchers. Wyland and D'Appolonia (1982) found spaghetti dried at 60, 70, and 80°C were firmer than spaghetti dried at 40°C, but no differences in spaghetti firmness were observed among the three high drying temperatures. Dexter et al (1984) found significantly lower cooking losses for spaghetti dried at 70°C compared to that of spaghetti dried at 39°C. No further reduction in cooking loss was observed with spaghetti dried at 80 and 85°C. Lower cooking losses were also reported by Abecassis et al (1989a) with high-temperature and low-moisture drying conditions. Abecassis et al (1984) found that color and cooking quality of spaghetti dried at 70 and 90°C were superior to those of spaghetti dried at 37°C, but improvements in quality between 70 and 90°C were slight. Seibel et al (1985) also reported marginal differences in cooking quality between spaghetti dried at 50 and 75°C. Manser (1983) concluded that a temperature of 68°C was optimum.

CONCLUSIONS

Cooking quality of spaghetti was affected by both semolina protein level and spaghetti drying temperature. Quality increased significantly as protein level increased. Spaghetti quality did not appear to be greatly improved with drying temperatures greater than 60°C for the drying cycles used in this study.

Contour plots generated from fitted regression equations for optimally cooked and overcooked spaghetti revealed that firmness and compression were primarily affected by protein level, while relaxation time was mainly affected by drying temperature. Cooking loss of optimally cooked spaghetti was primarily influenced by protein level, whereas cooking loss of overcooked spaghetti appeared to be influenced by both predictor variables.

Predicted responses of optimally and overcooked spaghetti met or exceeded cooking-quality values of commercial durum spaghetti samples, except for relaxation time and cooking loss. To achieve spaghetti of comparable commercial quality, drying temperatures greater than 60°C were required for low protein semolina. For protein levels greater than 14%, a drying temperature of 50°C was satisfactory. Further research should be undertaken to document the role of HT drying and semolina protein levels under commercial plant conditions. Drying temperatures greater than 90°C should also be examined because VHT drying lines are being adopted by the pasta industry.

TABLE V
Cooking Quality Measurements of Seven Commercial Durum Spaghetti Samples

	Range	
Quality Parameter	**Optimally Cooked**	**Overcooked**
Firmness (N)	4.7–5.7	3.3–4.6
Compression energy (N.mm)	2.0–2.4	2.7–3.4
Relaxation time (sec)	25–45	15–24
Cooking loss (%)	5.5–6.4	7.3–9.6

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