Chemical and Technological Variables and Their Relationships: A Predictive Equation for Pasta Cooking Quality[1]

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ABSTRACT

Fifty samples of 10 Italian durum wheat varieties were analyzed by technological and chemical tests and 26 variables were obtained; their value in predicting pasta cooking quality was investigated. Pasta was dried at two temperatures (40 and 80°C), and cooking quality was measured as organoleptic judgment (OJ) and total organic matter (TOM). Factor analysis was applied to the variables as a clustering tool; among the six factors identified, three were useful in describing the relationships among variables. The first, related to rheological characteristics (manual gluten quality, sodium dodecyl sulfate sedimentation test, and viscoelastographic, alveographic, and farinographic measurements), was defined as the quality factor. The second, associated with protein and gluten content, was called the quantity factor. Another factor (the sixth) was related mainly to cooking quality parameters of pasta dried at 40°C, whereas the quality parameters at 80°C were linked to the second factor. Multiple regressions were calculated to evaluate the combined effects of one variable from the quantity factor and one from the quality factor on OJ and TOM of pasta dried at 40 and 80°C. Among the many variables of gluten quality, manual evaluation and alveograph *W* value were the most efficient; for the quantity variable, protein content was used. The role played by these variables differed with drying temperature: at 40°C the quantity and quality variables had almost the same worth, but at 80°C protein content was prevalent. Predictive equations for pasta cooking quality were calculated with these variables and the values needed to produce a significant improvement in pasta cooking quality were found.

Durum wheat is the best raw material for processing into a pasta that usually has a good texture, resists surface disintegration, and retains a firm structure when cooked. However, not all durum wheat semolina produces pasta of good cooking quality; many variables are involved in pasta manufacturing, and their role is not completely understood. Efforts have been made to assess which single test or group of tests best predict cooking quality (Damidaux and Feillet 1978, Matsuo et al 1982). Many researchers (Matweef 1966, Matsuo and Irvine 1970, Walsh and Gilles 1971, Matsuo et al 1972, Grzybowski and Donnelly 1979) have established that content and composition of proteins, gluten strength in particular, are important for the cooking quality of pasta. Cooking quality was shown to depend on rheological properties related to gluten strength and on surface characteristics, but these parameters did not seem to be directly related (D'Egidio et al 1979, Feillet 1984). Their independence was conclusively demonstrated by Autran et al (1986). Several procedures using the viscoelastograph, alveograph, and farinograph have been proposed to evaluate the rheological properties on whole meal or semolina, but no method was developed for predicting surface characteristics until now. These characteristics can be determined only on cooked pasta by objective methods such as the total

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organic matter (TOM) test proposed by D'Egidio et al (1982), or the GRL compression test, highly correlated with TOM (Dexter et al 1983a, 1985).

The most reliable test for pasta cooking quality still remains sensory evaluation, because it gives an overall assessment of its characteristics, even if subject to individual bias (Cubadda 1988; Matsuo 1988).

Moreover it is important to note that the high-temperature drying systems, widely used nowadays in pasta manufacturing, influence the physicochemical characteristics of semolina, thus modifying pasta cooking quality (Dexter et al 1981, 1983b; Abecassis et al 1984).

Because many parameters and different drying systems are involved in determining pasta cooking quality, it has been considered fruitful to extend the knowledge about this topic. This experiment was carried out: 1) to evaluate the relationships between different technological and chemical variables and pasta cooking quality estimated by organoleptic judgment and by the TOM test; 2) to define the relative importance of the variables when different temperatures are used for drying pasta; and 3) to establish if the variables identified as most important can be usefully linked in an equation to predict pasta cooking quality.

MATERIALS AND METHODS

Plant Material

Ten durum wheat varieties (Appio, Appulo, Capeiti, Creso, Duilio, Karel, Latino, Quadruro, Valforte, and Valnova), field grown in different locations of central and southern Italy during 1986 were used; 50 samples were analyzed. All the samples were of pasta-making grade. The mean test weight was 79.2 ± 3.03 kg/hl with a range between 74.9 and 85.8. The falling number values were higher than 360 sec for all the samples.

Technological Tests

Wheat (50 kg) was cleaned, conditioned to a water content of 16%, and left moistened overnight. Standard milling was performed in a Buhler MCK mill with six breaking and six sizing passages. The normal semolina yield reached a value of approximately 70%.

The semolina was mixed with tap water to obtain a total dough water content of 32–33%. The dough was processed into spaghetti using a laboratory press (Serma) with a capacity of 1.5–3.5 kg for pilot plant and an experimental press (Barilla) with a capacity of 8–15 kg for industrial plant. Extrusion conditions were the same for the two presses: temperature was 50 ± 5°C, pressure was 60 ± 10 atm, and vacuum was 700 mmHg. Two drying procedures were applied: 20 hr at 40°C in the pilot plant, and 5 hr at about 80°C in the industrial plant (Fig. 1).

A standard cooking method was used: 100 g of spaghetti (1.7 mm thickness) was cooked in 1 L of boiling tap water without added salt for 13 min. Nine minutes after draining, spaghetti was evaluated by an organoleptic and chemical procedure.

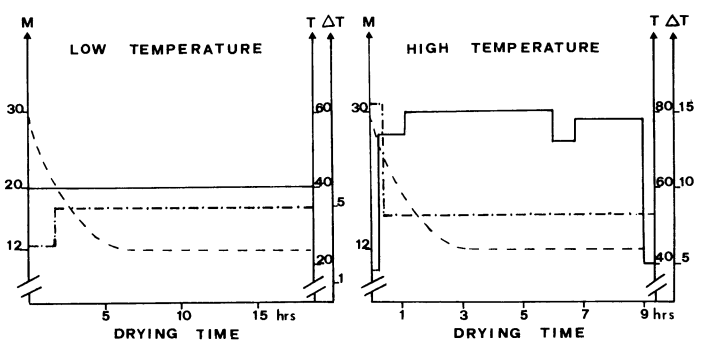

Fig. 1. Processing diagrams for low- and high-temperature drying. **M** = pasta moisture (%) (- - -); **T** = air temperature inside dryer (°C) (——); **ΔT** = difference between temperatures inside dryer on dry-bulb and wet-bulb thermometers (°C) (- · -).

The organoleptic judgment (OJ) was carried out by a trained panel of experts (three at least). Stickiness, bulkiness, and firmness were evaluated by each expert on a scale ranging from 10 (low quality) to 100 (very good quality). The means of the different evaluations (Cubadda 1988) were used for OJ estimation. All cooking tests were replicated three times in a laboratory under controlled temperature.

TOM, the surface material released from cooked pasta after exhaustive rinsing, was determined by a chemical method according to D'Egidio et al (1976, 1982).

Laboratory Tests

Grain utilized for protein and gluten content and for viscoelastographic measures was ground by a Buhler laboratory mill, and particle size was smaller than 325 μm.

Protein content of grain and semolina was determined by the Kjeldhal method (% N × 5.7, dry matter basis).

Gluten content (% wet gluten, dry matter basis) was determined on 20 g of grain by manual washing with a solution of NaCl 2% buffered at pH 6.8. The quality of gluten so extracted was evaluated by handling and classifying the degree of elasticity and extensibility with scores ranging from 0 to 10 as follows (Landi 1988): 0 = nonexistent; 1 = not cohesive; 2 = fragile, little cohesiveness, very sticky; 3 = fragile, not elastic, sticky; 4 = long, very extensible, not elastic; 5 = long, very extensible, little elasticity; 6 = medium, extensible, little elasticity; 7 = medium, slightly extensible, little elasticity; 8 = short, slightly extensible, elastic; 9–10 = short, tough, elastic.

Viscoelastographic evaluation of gluten was performed according to Damidaux and Feillet (1978). Elastic recovery

TABLE I
Mean Value and Standard Deviation of the Variables Considered[a]

Variables	Code	Mean	Range	SD
Pasta cooking quality				
Organoleptic judgment				
40°C (score)	OJ40	55	33–74	9.6
80°C (score)	OJ80	67	58–80	6.0
Total organic matter				
40°C (%)	TOM40	1.86	1.40–2.92	0.317
80°C (%)	TOM80	1.31	0.94–1.67	0.166
Grain				
Protein content (% dm)	GRPRO	13.1	11.1–18.4	1.53
Wet gluten content (% dm)	GRGLU	33.0	23.3–53.0	6.97
Manual gluten quality (score)	MGLUQ	6	3–9	1.8
SDS sedimentation test (ml)	SDS	44	29–71	10.0
Viscoelastograph parameters				
Gluten firmness (mm)	FIRM	3.21	2.37–4.07	0.357
Gluten elastic recovery (mm)	RECOV	1.28	0.69–1.90	0.299
Alveograph parameters				
W	GRW	175	62–303	72.5
P	GRP	108.2	48.5–152.9	33.29
G	GRG	15.3	11.4–23.0	2.36
P/*L*	GRPL	2.45	0.87–5.46	1.152
Semolina				
Protein content (% dm)	SEPRO	11.8	9.3–16.3	1.69
Alveograph parameters				
W	SEW	128	40–309	66.5
P	SEP	68.3	28.3–147.4	27.94
G	SEG	17.0	13.3–23.3	2.39
P/*L*	SEPL	1.23	0.43–2.85	0.611
Farinograph parameters				
A	SEA	55.3	48.1–61.5	3.35
B	SEB	165	90–330	50.9
CD	SECD	342	120–750	147.6
E10	SEE10	51	20–85	16.5
Protein fractions				
a (mg/g)	PRO1	27.0	12.0–60.8	11.98
b (mg/g)	PRO2	12.8	3.7–50.9	9.36
b/a (%)	PRO3	43.7	21.8–83.7	12.89

[a] $n = 50$.

(millimeters) and firmness (millimeters) were considered.

SDS sedimentation was performed according to Axford et al (1978) with a solution of 3% SDS (Dexter et al 1980).

Alveographic evaluation was performed on grain and semolina according to the standard method of Chopin, but dough was mixed for 4 min and, after a rest of 18 min, mixed again for 4 min. Grain was milled in a laboratory mill type 4 RB Bona (sieves 54 and 42 GG); the particle size was between 315 and 120 μm.

Farinograph curves for semolina were obtained with the Brabender apparatus. Water absorption (A), development time (B), degree of stability (CD), and softening (E10) were measured (Vannucchi 1986).

Protein fractions from semolina were extracted with diluted acetic acid and centrifuged as reported in D'Egidio et al (1982). Fraction "a" was the protein soluble in 0.1N acetic acid; fraction "b" was the protein precipitated from fraction a at pH 6.5 with 1N NaOH. The protein fractions were expressed as milligrams per gram of semolina on a dry basis.

Statistical Analysis

Simple correlations between all the variables were computed. Then a factor analysis was performed on the correlation matrix to identify a relatively small number of factors that could be used to represent the relationships among sets of many interrelated variables. This analysis was performed using the software package SPSS/PC+ Advanced Statistics (Norusis 1988) that allows the suitability of the factor model to be evaluated too.

Principal component analysis was used for factor extraction; the number of factors needed to adequately describe the data

	OJ 40	OJ 80	TOM 40	TOM 80	GRPRO	GRGLU	MGLUQ	SDS	FIRM	RECOV	GRW	GRP	GRG	GRPL	SEPRO	SEW	SEP	SEG	SEPL	SEA	SEB	SECD	SEE 10	PRO 1	PRO 2	PRO 3
PRO3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	31	ns	ns	ns	ns	ns	ns	ns	ns	64	83	100
PRO2	ns	ns	ns	ns	36	ns	ns	33	ns	ns	38	ns	ns	ns	40	ns	ns	37	ns	32	ns	ns	ns	93	100	
PRO1	ns	ns	ns	ns	45	29	ns	31	ns	ns	34	ns	36	ns	47	ns	ns	37	ns	35	34	ns	ns	100		
SEE10	ns	ns	ns	-31	ns	ns	-50	-39	ns	-46	-41	-39	ns	ns	ns	-45	-66	ns	-50	ns	-35	-79	100			
SECD	ns	ns	ns	ns	ns	ns	57	54	ns	55	49	48	ns	ns	ns	53	61	ns	37	ns	44	100				
SEB	ns	ns	ns	ns	ns	ns	39	42	-32	35	49	ns	49	ns	29	33	33	40	ns	37	100					
SEA	29	ns	ns	-43	67	52	ns	ns	-54	ns	51	41	ns	ns	76	34	48	ns	36	100						
SEPL	ns	ns	ns	ns	ns	ns	42	ns	ns	31	34	51	-39	59	ns	43	85	-58	100							
SEG	ns	ns	ns	ns	ns	ns	ns	56	ns	29	45	ns	68	-37	ns	ns	ns	100								
SEP	37	ns	-30	ns	ns	ns	62	45	ns	55	69	71	ns	48	ns	62	100									
SEW	38	ns	-33	ns	ns	ns	45	35	ns	38	53	51	ns	ns	ns	100										
SEPRO	30	43	ns	-62	95	84	ns	35	-52	ns	44	ns	38	ns	100											
GRPL	ns	ns	ns	ns	ns	-35	ns	ns	ns	39	29	73	-73	100												
GRG	ns	ns	-30	ns	44	38	ns	48	ns	ns	32	ns	100													
GRP	ns	ns	ns	ns	ns	ns	57	38	ns	69	81	100														
GRW	30	ns	-37	ns	33	ns	56	66	ns	69	100															
RECOV	ns	ns	ns	ns	ns	ns	52	57	-37	100																
FIRM	ns	ns	ns	ns	-50	-45	ns	ns	100																	
SDS	ns	ns	ns	ns	31	ns	56	100																		
MGLUQ	ns	ns	-32	ns	ns	ns	100																			
GRGLU	ns	46	ns	-56	88	100																				
GRPRO	37	52	ns	-60	100																					
TOM80	ns	-61	ns	100																						
TOM40	-74	ns	100																							
OJ80	ns	100																								
OJ40	100																									

Fig. 2. Correlation matrix of 26 durum wheat quality variables ($r \times 100$): ns = not significant, $r \geq 29$ = significantly different from zero at 5% probability, $r \leq 37$ = significantly different from zero at 1% probability.

was determined on the basis of eigenvalues and of percentage of the total variance accounted for by different factors. Eigenvalues greater than 1 were chosen, and a plot of the eigenvalues (scree plot) was also used to determine the number of factors to be considered. Moreover, a good fit between the factors and data was assured by estimating new correlation coefficients between the variables, by comparing them with the observed ones, and by determining the relative residuals. The magnitude of the residuals indicates how well the model fits the data.

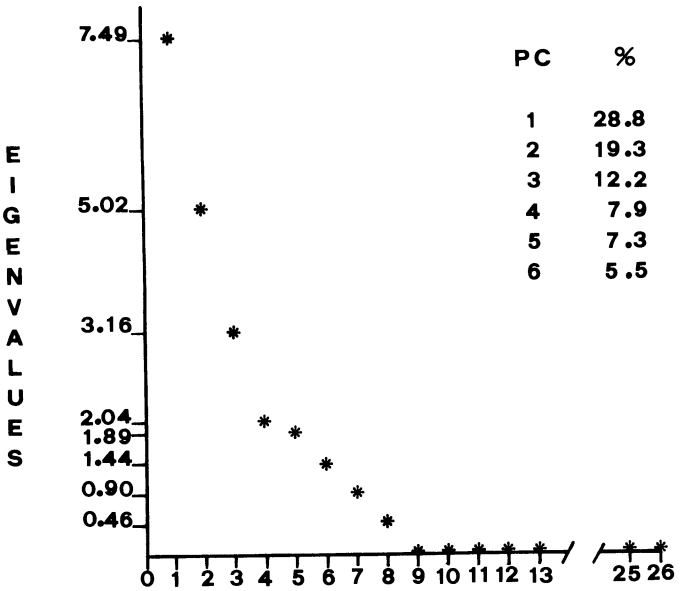

Fig. 3. Principal component analysis: scree plot and percentage of total variance accounted for by each principal component (**PC**).

TABLE II
Varimax Rotated Factor Matrix[a]

	Factor						Commu-nality
Code	1	2	3	4	5	6	(%)
SEE10	0.87						80
SECD	0.84						78
SEP	0.67						91
MGLUQ	0.61						65
SEB	0.60						59
SDS	0.54						69
RECOV	0.53		0.63				72
SEW	0.53						55
SEPL	0.50			−0.69			88
GRPRO		0.90					94
SEPRO		0.89					94
GRGLU		0.86					85
SEA		0.72					74
TOM80		−0.72					80
OJ80		0.68					64
FIRM		−0.64					68
GRP			0.89				94
GRPL			0.76	−0.58			95
GRW	0.50		0.69				91
SEG				0.91			92
GRG				0.81			87
PRO1					0.96		97
PRO2					0.87		77
PRO3					0.87		86
TOM40						0.89	83
OJ40						0.88	84
Eigenvalues	4.61	4.58	3.25	3.23	2.98	2.38	
% of total variance	17.7	17.6	12.5	12.4	11.5	9.2	

[a] Factor loadings on each of the six factors identified and communalities for each variable. Loadings less than 0.5 in absolute value are omitted. Below the matrix, the variance explained by each factor (eigenvalue) after rotation and the relative percentage on the total variance are displayed.

The varimax method was chosen for orthogonal factor rotation to minimize the number of variables having high loadings on a factor and to enhance the interpretability of the factors. As the rotation redistributes the variance of the extracted factors, eigenvalues and percentage of variance accounted for by each factor were calculated again.

The association among variables and factors measured by factor loadings can be graphically represented by plots in which orthogonal axes are the factors, taken two at a time, and coordinates of variables are the factor loadings. Thus, variables having high loadings on only one factor are related to it; variables near the origin of the axes, having small loadings on both factors, are not linked to them.

On the basis of the simple correlations and the factor analysis loads, two independent variables at a time were chosen from different factors to be used as predictor variables when multiple regressions were computed. The dependent variable was, alternatively, OJ or TOM, which can be referenced as criterion variables. Multiple correlations were calculated for the same sets of variables.

The best association of independent variables for estimating the dependent one was established by the reduction of deviation from multiple regression mean squares and by the significance of multiple correlation and partial regression coefficients. Then, standard partial regression coefficients were used to estimate the relative worth of the two independent variables involved (Steel and Torrie 1981). Finally the equations to predict the value of cooking quality (Y) were solved with the selected variables as X_1 and X_2. The 95% confidence limits for predicted values were computed according to Snedecor and Cochran (1980). Multiple correlations, multiple regressions, and predictive equations were calculated for pasta dried at 40 and 80° C.

RESULTS AND DISCUSSION

Relationships Between Variables

Mean, range of variability, and standard deviation of all the chemical and technological variables measured on 50 samples

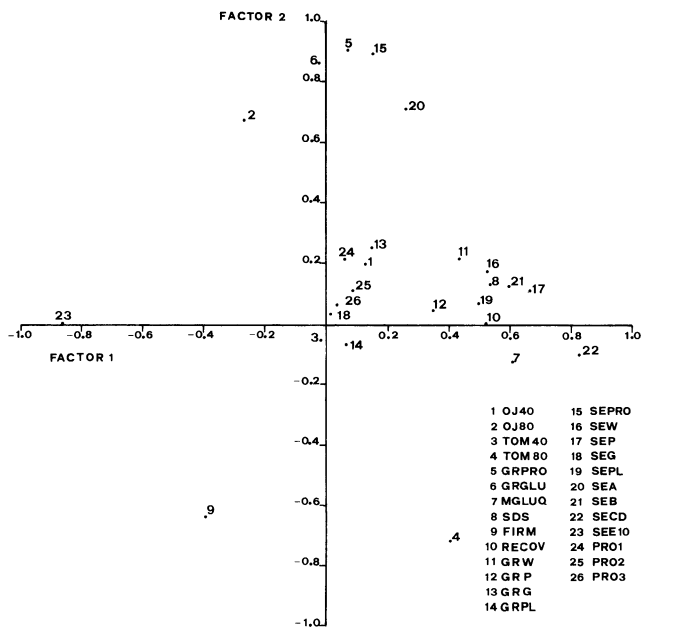

Fig. 4. Factor analysis: distribution of the 26 variables on the plot defined by factor 1 (= quality) and factor 2 (= quantity).

are reported in Table I; the variability values well reflect the qualitative diversity of Italian durum varieties.

Simple correlations among quality measurements for all possible pairs of variables are presented in Figure 2. The first four columns in this figure show the relationships between grain or semolina variables and cooking quality, as OJ and TOM, of pasta dried at 40 and 80°C. The significant negative correlation between OJ and TOM test for pasta at 40°C was confirmed when the higher drying temperature was used; TOM released in the rinse water decreased when spaghetti quality improved. Moreover, protein content was correlated with OJ and TOM both at 40 and 80°C. *W*, an alveographic measure of gluten quality, appeared to be related to cooking quality only of pasta dried at 40°C. The correlations between manual evaluation and all the other measures of gluten quality were significant both for grain and semolina; therefore manual evaluation, still widely used, results in a method that is valid although subjective and not easily standardizable. SDS sedimentation test was correlated with all the alveographic parameters and with protein content, too. As to viscoelastographic measures, gluten firmness was correlated with percentage of protein, gluten content, and farinogram A value; in contrast, gluten elastic recovery correlated only with gluten quality tests (*W* and *P* of alveogram; manual gluten quality; and B, CD, and E10 of farinogram).

Factor Analysis

Factor analysis, used to evaluate simultaneously all the variables and their relationships, was applied as a clustering tool to identify a few easily measured and unrelated variables to be included in multiple regressions that avoided multicollinearity effects (Steel and Torrie 1981).

The criterion variables (OJ and TOM) were included in the factor analysis to verify whether they were linked to predictor variables.

The results of principal component analysis and the scree plot presented in Figure 3 allowed six factors to be identified, explaining 81% of the total variance. As residuals between observed and estimated correlation coefficients greater than 0.05 were only 18%, the six-factor model fitted the data well.

The loadings of the six factors after orthogonal rotation and communalities for each variable are reported in Table II, which also shows the new distribution of the total variance for each factor. The first factor appears linked with manual gluten quality; SDS sedimentation test; alveogram *W* and *P* of semolina; and farinogram B, CD, and E10; thus it may be interpreted as the "quality" factor. The second factor is associated with protein and gluten content of grain and semolina, so it can be called the "quantity" factor. The farinogram A value and gluten firmness are loaded on this factor, too. Regarding criterion variables, it is important to note that OJ and TOM of pasta dried at 80°C are related to the quantity factor, whereas OJ and TOM of 40°C pasta have high loadings on the sixth factor. Other alveographic parameters, such as *W* and *P* of grain and gluten elastic recovery, are linked to the third factor, while *G* and *P*/*L* are on the fourth factor; some of these variables also load on factor 1. Finally, protein fractions are highly related to factor 5 (Table II).

TABLE III
Multiple Correlation and Partial Regression Coefficients for Protein Content and Several Measures of Gluten Quality on Cooking Quality of Pasta

Variables	Organoleptic Judgment			Total Organic Matter		
	Multiple Correlation	Partial Regression	Worth (%)	Multiple Correlation	Partial Regression	Worth (%)
Dried at 40°C						
Grain						
Protein content	0.478**[a]	2.419**	56	0.416*	−0.055	44
Manual gluten quality		1.574*	44		−0.058*	56
Protein content	0.420*	1.944*	60	0.393*	−0.031	32
W		0.027	40		−0.001*	68
Protein content	0.411*	2.010*	64	0.269	−0.046	70
SDS sedimentation test		0.172	36		−0.003	30
Protein content	0.402*	2.319**	72	0.302	−0.051	60
Gluten elastic recovery		4.705	28		−0.175	40
Semolina						
Protein content	0.429**	1.216	40	0.359*	−0.027	33
W		0.046*	60		−0.001*	67
Dried at 80°C						
Grain						
Protein content	0.548**	2.039**	76	0.613**	−0.065**	82
Manual gluten quality		−0.534	24		0.012	18
Protein content	0.560**	2.332**	74	0.599**	−0.064**	97
W		−0.018	26		0.001	3
Protein content	0.544**	−2.251**	78	0.642**	−0.073**	73
SDS sedimentation test		−0.095	22		0.004	27
Protein content	0.547**	2.088**	77	0.610**	−0.066**	84
Gluten elastic recovery		−3.239	23		0.065	16
Semolina						
Protein content	0.438**	1.612**	86	0.622**	−0.063**	87
W		−0.007	14		0.001	13

[a]* $P = 0.05$, ** $P = 0.01$.

Factor analysis distributes the 26 variables considered on the six factors extracted, clearly subdividing the measures of quality from those of quantity. This suggests that association of a quality and a quantity variable be utilized for evaluating pasta cooking quality. As the first two factors account for 35% of the total variance after rotation and well discriminate the quality from the quantity variables, the plot of Figure 4 can be considered exhaustive to describe the relationships among variables. Gluten quality parameters are clustered near the positive end of the horizontal factor 1. On the contrary, protein and gluten content are at the positive end of vertical factor 2. It can be noted that OJ and TOM at 80°C lie opposite each other on the vertical axis, as expected from their negative correlation. OJ and TOM at 40°C are near the origin of the plot, having small loadings on both factors; these variables are associated with the sixth factor.

Cooking Quality and Predictive Power of Variables

On the basis of factor analysis results, the combined effect of one measure of the quantity and one of the quality with OJ or TOM at 40 and 80°C was evaluated by multiple correlations. Protein content was chosen as the quantity variable and manual gluten quality, *W*, SDS sedimentation, and elastic recovery were alternatively used as the quality variable.

As shown in Table III, the highest correlation coefficient for OJ at 40°C was found in grain when protein content was associated with manual gluten quality; partial regression coefficients were significant too. Lower correlation coefficients were obtained, and the significance of partial regression coefficients disappeared when the manual gluten quality was replaced with *W*, SDS sedimentation, and elastic recovery. Besides, the relative worths presented in Table III show that protein content and gluten quality parameters, except elastic recovery, were almost equally useful (ratio 1:1) in estimating the OJ of 40°C pasta.

For TOM estimation, multiple correlation coefficients (Table III) were significant only for protein content combined with manual gluten quality or *W*. From partial regression coefficients, the quality variable, especially *W*, appeared to be more important than protein content and better related to the surface characteristics of cooked pasta. Similar comments apply to measures on semolina (Table III).

Hence, evaluating jointly the results for OJ and TOM, protein content and manual gluten quality or *W* were chosen to predict cooking quality of pasta dried at 40°C. Table III also gives the results of multiple correlations for pasta dried at 80°C. For grain and semolina, multiple correlation coefficients were highly significant; partial regression coefficients and relative worths indicated that protein content was almost three times as useful as each gluten quality measure in determining OJ and TOM.

Comparing the two drying temperatures, it appears that cooking quality of 40°C pasta is clearly a function of protein content and gluten quality, whereas at 80°C the protein assumes primary importance. This is in agreement with the results of Matsuo (1985, 1988). Moreover, it is known that high-temperature drying systems produce protein coagulation before cooking; the protein network so formed prevents starch granules from escaping during cooking (Dalbon 1983). This would explain why the protein content is the most effective variable when high temperatures are utilized.

Predictive Equations for Cooking Quality

The equations for predicting pasta quality were calculated using protein content and manual gluten quality or *W* for 40°C pasta and only protein content for 80°C (Table IV). The gluten quality variable was omitted from the predictive equation at 80°C, because the partial regression coefficients were not significant in our sample and relative worths were low. These findings are also in agreement with the results of factor analysis that linked OJ and TOM of 80°C pasta to the quantity factor. For low-temperature drying, Damidaux and Feillet (1978) suggested a similar equation but evaluated cooking quality on dough disks instead of spaghetti. Matsuo et al (1982) defined protein content and gluten quality as prerequisites for superior cooking quality.

Predicted values on the basis of the equations in Table IV and their 95% confidence limits for OJ and TOM (Table V) were computed using given values of protein content and gluten quality as X_1 and X_2.

For pasta dried at 40°C, when protein content and manual gluten quality were increased by 1 unit, or *W* by 50 units, OJ increased by 4 units and TOM decreased by 0.10 g. However, for OJ the confidence limits of predicted values allow a difference of 8 units to be significant; this can be obtained by an increase of 2 units for both protein content and manual gluten quality or of 100 units for *W*. The same improvements were necessary for a significant decrease (0.20 g) of TOM. These significant differences are similar to those (10 units and 0.20 g, respectively) obtained from many samples of different origin analyzed since 1975 and chosen to define classes to be used for cooking quality evaluation (D'Egidio et al 1987).

For pasta dried at 80°C (Table V) a one unit improvement in protein content produced effects on OJ and TOM only half of those on 40°C pasta, but low levels of protein (11% dm) are sufficient to obtain pasta of acceptable quality (OJ = 63 ± 3). It is important to note that the value of protein (15%) that produces an acceptable pasta at 40°C gives a very good quality (OJ = 71 ± 2) at 80°C.

It must be pointed out that the results for high temperatures are dependent on the combination of temperature, humidity, and time characterizing the drying diagram; variations in these three parameters can induce different degrees of quality improvement (Resmini et al 1988).

TABLE IV
Predictive Equations[a] for Pasta Cooking Quality at Different Drying Temperatures

Sample	$Y = a + (b_1 \cdot X_1) + (b_2 \cdot X_2)$
Grain	
40°C	
Judgment[b]	= 13.29 + 2.42 protein + 1.57 manual gluten quality
Judgment	= 24.61 + 1.94 protein + 0.03 *W*
TOM[c]	= 2.939 − 0.055 protein − 0.058 manual gluten quality
TOM	= 2.513 − 0.031 protein − 0.001 *W*
80°C	
Judgment	= 44.05 + 2.04 protein
TOM	= 2.082 − 0.065 protein
Semolina	
40°C	
Judgment	= 34.64 + 1.22 protein + 0.05 *W*
TOM	= 2.362 − 0.027 protein − 0.001 *W*
80°C	
Judgment	= 49.37 + 1.61 protein
TOM	= 2.020 − 0.063 protein

[a] Y = Cooking quality, X_1 = protein content, and X_2 = measure of gluten quality.
[b] Organoleptic judgment.
[c] Total organic matter.

TABLE V
Expected Values and Their 95% Confidence Limits of Judgment and TOM[a] for Given Values of Protein Content and Gluten Quality

Drying Temperature/ Judgment	Protein (% dm)	Gluten Quality		TOM[a]
		Manual	*W*	
40°C				
54 ± 2	13	6	175	1.86 ± 0.08
58 ± 3	14	7	225	1.76 ± 0.10
62 ± 5	15	8	275	1.66 ± 0.16
80°C				
63 ± 3	11	...	...	1.45 ± 0.07
65 ± 2	12	...	...	1.38 ± 0.05
67 ± 2	13	...	...	1.32 ± 0.04
69 ± 2	14	...	...	1.25 ± 0.04
71 ± 3	15	...	...	1.19 ± 0.06

[a] Total organic matter.

CONCLUSIONS

This investigation allowed the identification of two factors from all the variables involved, one for quality and one for quantity. It also enabled us to choose, within each factor, the variable best associated with pasta cooking quality, i.e., protein content and manual gluten quality or *W*. We studied the role played by these variables under two drying temperatures: at 40°C the ratio between protein content and gluten quality was about 1:1 while at 80°C it became 3:1. It was possible to formulate predictive equations for pasta cooking quality expressed as OJ and TOM at 40 and 80°C and to define significant differences for evaluating cooking quality.

The different responses obtained with low and high temperatures confirmed the importance of the raw material characteristics (protein content and gluten quality) when a traditional system is used. In contrast, with high temperatures, the technological process appears to prevail on the intrinsic characteristics and protein content assumes a primary importance.

Finally, we conclude that it is a valid goal for breeding to improve the intrinsic characteristics of durum wheat varieties by enhancing the present levels of protein content and gluten quality because only good raw material always assures good pasta. The variables chosen for predictive equations can be fruitfully utilized in selecting new lines, but in early selection, gluten quality can be determined by manual evaluation only, more seed being required for evaluating *W*. There are, however, different measures of gluten quality, such as the SDS sedimentation test and gliadin electrophoregrams, that are not efficient to predict pasta cooking quality but allow screening for poor material.

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