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Viscoelastograph Measures and Total Organic Matter Test: Suitability in Evaluating Textural Characteristics of Cooked Pasta

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ABSTRACT

Two sets of Italian durum wheats were used to make spaghetti: 54 samples dried at low temperature (50°C) and 64 samples dried at high temperature (90°C). Cooking quality was evaluated using sensory judgment (SJ), total organic matter (TOM), and viscoelastograph parameters. SJ was expressed by its components (stickiness, bulkiness, and firmness) and by an overall score. Factor analysis was applied as a clustering tool to assess similar behavior of variables. Four factors were useful in describing the relationships among variables for each temperature considered. At 50°C the first factor was related to viscoelastograph parameters, the second grouped SJ, stickiness, bulkiness, and TOM, whereas firmness was linked to a different factor. At 90°C firmness was associated with stickiness, bulkiness, and SJ on the second factor, whereas TOM shifted to another factor. Multiple regressions were calculated to evaluate the relative worths of stickiness, bulkiness, and firmness on SJ and TOM as well as their relationships with viscoelastograph measures when different drying temperatures were applied. At low temperature, stickiness was the most important SJ component and TOM was a suitable method in estimating SJ. At high temperature, firmness played a more important role and viscoelastograph consistency was used to complement the TOM test.

Textural characteristics of cooked pasta are of primary importance in defining pasta quality. Among the characteristics, firmness, compressibility, elasticity, and surface stickiness have received the greatest attention, and different objective methods have been used to measure these parameters (Matsuo and Irvine 1969, 1971, 1974; Feillet et al 1977; Voisey et al 1978a,b; D'Egidio et al 1982; Dexter et al 1983, 1985). Matsuo and Irvine (1969, 1971) developed a Grain Research Laboratory (GRL) tenderness testing apparatus to measure tenderness, compressibility, and recovery of cooked pasta. Voisey and Larmond (1973) studied the relations between sensory parameters and instrumental measures obtained from Instron and Ottawa measuring systems. Subsequently, Matsuo and Irvine (1974) reported the good relationships of GRL apparatus readings with the sensory evaluations obtained by Voisey and Larmond (1973). Dexter et al (1983) adapted the GRL tester to measure cooked spaghetti stickiness, and then Dexter et al (1985) found their instrumental measures well related to the total organic matter (TOM) test of D'Egidio et al (1982). Feillet et al (1977) applied the viscoelastograph to the determination of viscoelastic properties of cooked

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pasta. This is a routine method used by the Institut National de la Recherche Agronomique (Montpellier, France) to estimate pasta quality, jointly with evaluation of surface properties obtained by reference photographs.

The viscoelastograph is easy to use and widely employed, but no correlation between viscoelastograph parameters and sensory textural characteristics have been reported. As sensory analysis is usually considered the reference method to judge the suitability of any objective measure, this work was performed 1) to compare viscoelastograph parameters and the TOM test with sensory judgment (SJ) and 2) to define the relative importance of these parameters on SJ when different temperatures for drying pasta are used.

MATERIALS AND METHODS

Plant Material

Two different sets of durum wheats were considered. The first one was composed of 54 samples obtained from 30 varieties grown at three locations in Italy during 1989; 16 varieties were the same in all three environments. The second set was of 64 samples obtained from 30 varieties grown during 1990 at three locations different from those of 1989; 10 varieties were the same in all three locations. Four varieties were common in the two sets; therefore, 56 varieties representative of the main Italian durum wheats were considered. All of the samples (n = 118), grown in experimental trials, were analyzed separately and were of pasta-making grade.

Spaghetti from the 54 samples of 1989 was dried at low temperature (50°C) and that from the 64 samples of 1990 was dried at high temperature (90°C).

The samples of the first set, dried at 50°C, had the following average grain characteristics: test weight = 78.9 kg/hl (range: 77.3–81.0 kg/hl), ash = 2.0% dm (1.86–2.26%), SDS sedimentation test = 34 ml (20–49 ml), alveogram W = 167 $J \cdot 10^{-4}$ (50–297 $J \cdot 10^{-4}$), and protein content = 13.3% dm (10.7–17.4%).

For samples of the second set, dried at 90°C, the grain characteristics were as follows: test weight = 80.4 kg/hl (range 78.2–83.5 kg/hl), ash = 1.86% dm (1.66–2.00%), SDS sedimentation test = 43 ml (18–55 ml), alveogram W = 156 $J \cdot 10^{-4}$ (43–302 $J \cdot 10^{-4}$), and protein content = 14.7% dm (12.6–17.4%).

Analytical Test

Grain protein content was determined by the Kjeldahl method (percent N × 5.7, dm basis).

Technological Tests

Wheat (25 kg) was cleaned, conditioned to a water content of 16%, and left to moisten overnight. Standard milling was performed in a Buhler MCK mill (Buhler, Uzwil, Switzerland) with three breaking and three 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

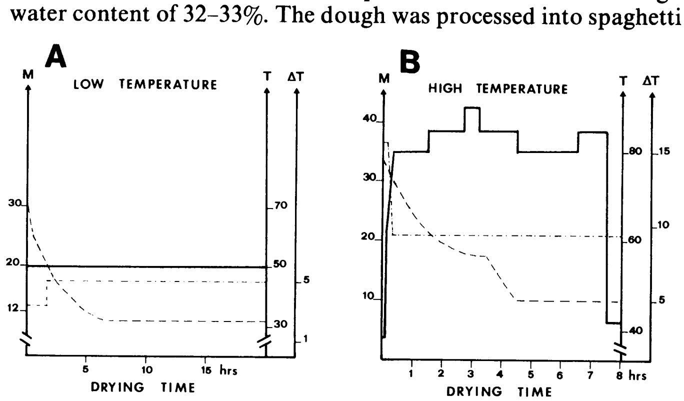

Fig. 1. Processing diagrams for low- and high-temperature drying (**A** and **B**, respectively). M = percent pasta moisture (- - -), T = air temperature (°C) inside dryer (——), ΔT = difference between temperatures (°C) inside dryer on dry- and wet-bulb thermometers (–·–·–).

using a laboratory press (Serma, Milano, Italy) with a capacity of 1.5–3.5 kg (pilot plant) and an experimental press with a capacity of 8–15 kg (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: 18 hr at 50°C in the pilot plant and 7 hr at about 90°C in the industrial plant (Fig. 1).

The following cooking method was used: 100 g of spaghetti (1.7 mm thickness, 20 cm length) was cooked in 1 L of boiling tap water (total hardness = 18 German degrees [1 German degree = 1 g of CaO in 100 L of H_2O]) without added salt for 13 min. Nine minutes after draining, spaghetti quality was evaluated. All cooking tests were made in a laboratory under controlled temperature and replicated two times. A third replication was considered when the difference of SJ between the two replications was higher than 10%.

Cooked Pasta Measurements

SJ. The SJ was performed by a highly trained panel of three experts. The general test conditions (order and presentation of samples, etc.) were according to international standard 7304 (ISO 1985).

The following textural parameters were considered (Cubadda 1988): stickiness, the material adhering to surface of cooked pasta evaluated by visual inspection with the aid of standard reference samples and by handling; bulkiness, which is related to stickiness, the adhesion degree of pasta strands to each other evaluated visually and manually; and firmness, the resistance of cooked pasta to chewing by the teeth. Each of these three parameters was evaluated by a score ranging from 10 to 100. For stickiness and bulkiness, ≤20 = very high, 40 = high, 60 = rare, 80 = almost absent, and 100 = absent. For firmness, ≤20 = absent, 40 = rare, 60 = sufficient, 80 = good, and 100 = very good.

The score of each SJ component was the arithmetic mean of the values given by the three assessors; the final value of SJ was the average of the means of stickiness, bulkiness, and firmness.

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

Viscoelastograph. The viscoelastograph measurements were performed, according to Feillet et al (1977), by applying a constant load of 500 g on five spaghetti strands for each sample and then calculating their mean. The following parameters were obtained from viscoelastograph curves: compressibility = $(E - e_1)/E$, consistency = $100(e_1/E)$, absolute recovery = $e_2 - e_1$, relative recovery = $(e_2 - e_1)/(E - e_1)$, recovery degree = $(e_2 - e_1)/E$, and index (relative recovery/compressibility) = $100E[(e_2 - e_1)/(E - e_1)^2]$. E is the initial spaghetti thickness, e_1 is the thickness after the loading-on time, and e_2 is the final thickness after the loading-off time.

Statistical Analysis

Simple correlations between all variables were computed at the two different drying temperatures.

Factor analysis was performed by the IBM scientific subroutine package on the correlation matrix to evaluate simultaneously all of the variables and their relationships. Principal component analysis was used for factor extraction; the number of factors needed to adequately describe the data was determined on the basis of eigenvalues and percentage of the total variance accounted for by different factors. Eigenvalues greater than 0.7 were chosen by looking at the pattern of variables on the factors (Kendall 1975).

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.

Multiple regressions and correlations were computed to estimate the combined effect of the SJ components on SJ and to clarify the relationships of these components on TOM and two viscoelastographic measures chosen, i.e., consistency and relative recovery. Moreover, multiple regressions and correlations were calculated using consistency and relative recovery as independent variables. The dependent variable was alternately stickiness, bulkiness, or firmness. Finally, the two viscoelastographic measures chosen and TOM were correlated with SJ at 50 and 90°C.

Coefficients of multiple correlation were used to evaluate the suitability of the chosen regressions, and standard partial regression coefficients were computed to estimate the relative worths of the independent variables involved (Steel and Torrie 1960). Since each standard partial regression coefficient is independent of the original units of measurement, a comparison of the standard partial regression coefficients indicates the relative importance of the independent variables involved. To simplify this comparison, these standard partial regression coefficients (relative worths) were expressed as percentages of their total.

Since the two sets of samples were different for year, locality, variety, and protein content, the relative worths of stickiness, bulkiness, and firmness on SJ were tested also on a larger set of samples ($n = 216$) grown in Italy from 1987 to 1990 and dried both at low and high temperatures.

Moreover, to demonstrate that protein content had negligible effect on relative worths, multiple regressions were calculated including protein content as a fourth regressor variable jointly with stickiness, bulkiness, and firmness.

RESULTS AND DISCUSSION

Relationships Between Variables

Mean, standard deviation, and range of variability of all sensory, chemical, and viscoelastograph variables measured on the two sets of samples dried at 50 and 90°C are reported in Table I. It shows the lower variability of the 64 samples dried at 90°C and the shifting of the variables to more favorable values than those at 50°C according to the results obtained by D'Egidio et al (1990).

Simple Correlations for 50°C

Correlation coefficients for the considered variables at 50°C are presented in Table II. As expected, SJ and TOM are related negatively. In contrast, stickiness, bulkiness, and firmness are positively associated with SJ. The correlation coefficient between firmness and SJ is lower than those between SJ and stickiness or bulkiness; the same trend is obtained when stickiness, bulkiness, and firmness are correlated with TOM.

All viscoelastograph measures appear linked with SJ: the two consistency variables (consistency and compressibility) show association values higher in absolute value than those of elasticity measures (relative recovery, recovery degree, and absolute recovery). For the SJ components, the two consistency variables are linked to stickiness, bulkiness, and firmness at the same level, whereas the elasticity measures are correlated only with stickiness and bulkiness. These results are in agreement with those obtained by Matsuo and Irvine (1974), who found a negative correlation between sensory firmness and compressibility measured by the GRL tester, but they are in contrast with the relationship found by the same authors between firmness and recovery. The correlation coefficient between consistency and compressibility is equal to −1 because the two variables measure, by different formula, the same character, i.e., resistance of cooked spaghetti to compression. For this reason, correlation coefficients between consistency or compressibility and all of the other variables are analogous but of opposite sign.

Index, obtained from elasticity and consistency measures, is highly correlated with all of the viscoelastographic parameters.

TABLE I
Mean Value, Standard Deviation, and Range of the Variables Considered at 50 and 90°C[a]

	50°C			90°C		
Variable	Mean	SD	Range	Mean	SD	Range
Sensory judgment (score)	63	7.6	46–76	82	6.1	67–93
Total organic matter, %	2.13	0.337	1.70–2.80	1.30	0.201	0.95–1.77
Stickiness (score)	61	12.1	33–83	84	6.2	63–97
Bulkiness (score)	59	7.5	40–77	77	6.3	60–90
Firmness (score)	68	7.4	50–80	85	8.0	70–100
Viscoelastograph parameters						
Compressibility, mm	0.55	0.046	0.45–0.69	0.40	0.027	0.35–0.46
Consistency, %	45	4.7	31–55	60	2.7	54–65
Absolute recovery, mm	0.67	0.110	0.37–0.86	0.70	0.040	0.60–0.78
Relative recovery, mm	0.55	0.116	0.23–0.73	0.75	0.025	0.68–0.82
Recovery degree, mm	0.30	0.045	0.16–0.36	0.30	0.017	0.26–0.34
Index, %	102	29.1	33–161	188	16.4	150–223

[a] At 50 and 90°C, $n = 54$ and 64, respectively.

TABLE II
Correlation Matrix of 12 Durum Wheat Variables[a] ($r \times 100$) at 50°C[b]

Variable	SJ	TOM	STICK	BULK	FIRM	COMPR	CONSI	RECOV	RECRE	RECDE	IND	GRPRO
GRPRO	37	NS[c]	33	35	NS	−60	59	61	66	56	71	...
IND	49	−46	47	45	NS	−94	94	88	98	88	...	
RECDE	35	NS	42	34	NS	−72	73	98	95	...		
RECRE	45	−44	46	42	NS	−89	89	94	...			
RECOV	29	NS	36	28	NS	−71	72	...				
CONSI	54	−45	46	48	44	−100	...					
COMPR	−53	45	−45	−47	−44	...						
FIRM	66	−58	40	46	...							
BULK	89	−77	83	...								
STICK	93	−93	...									
TOM	−94	...										
SJ	...											

[a] SJ, sensory judgment; TOM, total organic matter; STICK, stickiness; BULK, bulkiness; FIRM, firmness; COMPR, compressibility; CONSI, consistency; RECOV, absolute recovery; RECRE, relative recovery; RECDE, recovery degree; IND, index; GRPRO, grain protein content.
[b] Only significant values are reported.
[c] NS = Not significant; $|r| \geq 27$ ($P = 0.05$), $|r| \geq 35$ ($P = 0.01$).

TABLE III
Correlation Matrix of 12 Durum Wheat Variables[a] ($r \times 100$) at 90°C[b]

Variable	SJ	TOM	STICK	BULK	FIRM	COMPR	CONSI	RECOV	RECRE	RECDE	IND	GRPRO
GRPRO	53	−39	42	38	49	−45	45	NS[c]	33	−33	45	...
IND	59	−50	51	41	56	−95	95	−62	76	−67	...	
RECDE	−49	37	−40	−43	−43	86	−86	88	NS	...		
RECRE	37	−37	34	NS	40	−54	54	NS	...			
RECOV	−28	34	−28	NS	NS	77	−77	...				
CONSI	60	−50	51	46	57	−100	...					
COMPR	−60	50	−51	−45	−57	...						
FIRM	86	−48	67	57	...							
BULK	82	−29	62	...								
STICK	87	−53	...									
TOM	−52	...										
SJ	...											

[a] SJ, sensory judgment; TOM, total organic matter; STICK, stickiness; BULK, bulkiness; FIRM, firmness; COMPR, compressibility; CONSI, consistency; RECOV, absolute recovery; RECRE, relative recovery; RECDE, recovery degree; IND, index; GRPRO, grain protein content.
[b] Only significant values are reported.
[c] NS = Not significant; $|r| \geq 25$ ($P = 0.05$), $|r| \geq 32$ ($P = 0.01$).

TABLE IV
Varimax Rotated Factor Matrix[a]

Variable	Factors at 50°C 1	2	3	4	Communality (%)	Factors at 90°C 1	2	3	4	Communality (%)
Relative recovery	0.97				99			0.96		99
Recovery degree	0.96				96	−0.93				98
Index	0.96				99	0.63		0.68		100
Absolute recovery	0.93				87	−0.95				92
Consistency	0.88				91	0.80				99
Compressibility	−0.88				91	−0.80				99
Stickiness		0.96			95		0.76			77
Sensory judgment		0.95			97		0.90			98
Total organic matter		−0.90			95				0.83	80
Bulkiness		0.86			82		0.88			82
Grain protein content			0.89		94				−0.63	56
Firmness				0.91	98		0.74			75
Cumulative variance, %	45	76	84	93		31	57	73	87	

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

TABLE V
Multiple Correlation (*R*), Partial Regression Coefficients (*b*), and Relative Worths (*w*) of the Three Characteristics of Cooked Pasta in Relation to Sensory Judgment

	50°C *R*	*b*	*w* (%)	90°C *R*	*b*	*w* (%)
Stickiness		0.37**[a]	51		0.37**	33
Bulkiness	0.99**	0.27**	23	0.99**	0.35**	32
Firmness		0.31**	26		0.30**	35

[a] $P = 0.01$ for **.

Grain protein content appears more closely linked with viscoelastographic measures (particularly with index) than with SJ and its components.

Simple Correlations for 90°C

Correlation coefficients for the variables at high temperature are shown in Table III. The association between SJ and TOM is lower than that found at 50°C according to the results reported by D'Egidio et al (1990).

Correlation coefficients of stickiness, bulkiness, and firmness with SJ are similar because of the increased association between firmness and SJ. The correlations between the three sensory components and TOM are lower than those at 50°C.

The viscoelastograph measures appear better linked with SJ and, among the SJ components, with firmness at 90°C than at 50°C (except relative recovery).

The association between index and the elasticity measures (absolute recovery, relative recovery, and recovery degree) is lower at 90°C than at 50°C, probably because high temperature influences compressibility and elasticity with a different degree.

Grain protein content is better linked with SJ and its components at 90°C. We think this result is not due as much to the higher protein content of the samples at 90°C as to the effect of the high-temperature drying system. In fact, D'Egidio et al (1990) demonstrated an improvement in pasta cooking quality at high temperature also with low levels of protein content.

Factor Analysis

Factor analysis applied as a clustering tool (Table IV) allows four factors to be identified, explaining 93 and 87% of the total variance, respectively, for 50 and 90°C. At 50°C, factor 1 links all of the viscoelastograph measures; factor 2 is associated with SJ, stickiness, bulkiness, and TOM; protein content loads on factor 3; and sensory firmness loads on factor 4. The variables associated with factor 2 show SJ expressed essentially by surface characteristics that appear to be well measured by TOM (as indicated also by the high value of correlation between SJ and TOM at 50°C). Firmness, an expression of resistance to bite, is independent of surface characteristics having high loading on another factor; this explains the lower correlation value with SJ (Table II).

The results differ when high temperature is applied: firmness is linked to factor 2 together with SJ, stickiness, and bulkiness, whereas TOM shifts on factor 4. Therefore, firmmess assumes the same worth as stickiness and bulkiness in determining the overall cooking quality judgment, whereas the functional

TABLE VI
Relative Worths (w) of the Three Characteristics of Cooked Pasta on Sensory Judgment With and Without Protein Content as the Fourth Regressor Variable[a]

	1989[b]		1990		1987–1990	
	w, Three Variables (%)	w, Four Variables (%)	w, Three Variables (%)	w, Four Variables (%)	w, Three Variables (%)	w, Four Variables (%)
50°C						
Stickiness	51	50.9			48	47
Bulkiness	23	26.0			28	28
Firmness	26	22.8			23	23
Protein content	...	0.2			...	2
90°C						
Stickiness			33	32	37	37
Bulkiness			32	31	32	32
Firmness			35	33	31	30
Protein content			...	4	...	1

[a] The 1989 and 1990 sets are the two sets used in this work; the 1987–1990 set is presented to confirm the results obtained on the first two.
[b] $n = 54$, 64, and 216 for 1989, 1990, and 1987–1990, respectively.

relationship between SJ and TOM decreases. This is because the high-temperature drying system modifies the relative importance of the three SJ components, decreasing the worth of stickiness and bulkiness on SJ.

The viscoelastograph measures remain on the first factor, except index and relative recovery, which shift to factor 3. As a general trend, at low as well as at high temperature, these measures are loading on factors different from those of SJ and its components.

Multiple Correlations

Multiple correlations between stickiness, bulkiness, and firmness (considered independent variables) and SJ (obtained as their mean value) were calculated (Table V) to understand whether these characteristics of cooked pasta had a different relative worth on SJ when different drying temperatures were applied. At 50°C, SJ appears determined essentially by stickiness, which has a relative worth higher than that of bulkiness and firmness; at 90°C, in contrast, the three SJ components have similar relative worth in determining SJ.

These different relative worths of SJ components at low and high temperatures also were found similar on a larger set of samples ($n = 216$) obtained from different varieties and locations over four years (Table VI), confirming that the results were not influenced as much by the effects of year, location, and variety as by different drying systems.

The relative worth of protein content, a variable particularly influenced by environment and very important when high temperatures are used for pasta manufacturing (D'Egidio et al 1990), on SJ (in respect of the three SJ components) is negligible: the worths for stickiness, bulkiness, and firmness follow the same pattern when protein content is or is not included in the multiple regressions (Table VI).

These results substantiate our claim that variations in year and protein content did not affect the relative relationships of stickiness, bulkiness, and firmness on SJ; consequently, these relationships can be used as a reference to evaluate the suitability of instrumental methods proposed at low and high temperatures.

Before considering the multiple correlations between SJ components and viscoelastograph measures, it can be noted that two viscoelastograph parameters only are considered: consistency and relative recovery. Consistency was chosen because it is positively related to the variables considered (Tables II and III), relative recovery because it expresses the capacity of spaghetti to recover thickness as a function of deformation and because, at high temperature, this measure appears to be distinct from the other viscoelastograph parameters loading on a different factor in factor analysis (Table IV).

Multiple correlations of the three SJ components on TOM and the two viscoelastograph measures are reported in Table VII. At low temperature, TOM is highly influenced by stickiness, whereas firmness has a lower relative worth but is statistically significant. At high temperature, the multiple correlation coefficient decreases. The relative worth of stickiness in determining TOM is lower, whereas that of firmness increases. These results confirm that TOM is essentially a measure of stickiness, which has the highest relative worth on SJ at 50°C; consequently, TOM can be considered a very suitable measure of total cooking quality evaluation at low temperature (D'Egidio et al 1978).

TABLE VII
Multiple Correlation Coefficients (R), Partial Regression Coefficients (b), and Relative Worths (w) of the Three Characteristics of Cooked Pasta in Relation to Total Organic Matter and Two Viscoelastograph Parameters

	50°C			90°C		
	R	b	w (%)	R	b	w (%)
Total organic matter						
Stickiness		−0.021**[a]	68		−0.014**	53
Bulkiness	0.97**	−0.005	10	0.56**	0.004	15
Firmness		−0.017**	21		−0.006*	32
Consistency						
Stickiness		0.07	28		0.08	26
Bulkiness	0.55**	0.12	30	0.61**	0.06	20
Firmness		0.18*	42		0.13*	54
Relative recovery						
Stickiness		0.003	...		0.001	30
Bulkiness	0.47**	0.002	...	0.42**	−0.001	19
Firmness		−0.000	...		0.001*	51

[a] $P = 0.05$ and 0.01 for * and **, respectively.

Firmness appears linked to consistency both at low and high temperatures and to relative recovery at high temperature only (Table VII), suggesting that these two measures are essentially an expression of firmness.

To evaluate jointly the importance of consistency and relative recovery on SJ components at low and high temperatures, multiple correlation coefficients, partial regression coefficients, and relative worths are presented in Table VIII.

At 50°C, consistency and relative recovery have almost the same importance in estimating firmness; at 90°C, consistency only is important because there is no apparent relationship between firmness and relative recovery when consistency is held constant. As evidenced from partial regression coefficients, neither consistency nor relative recovery have worth on stickiness and bulkiness at 50°C; at 90°C, consistency only assumes significant importance (Table VIII).

A high-temperature drying system determines an overall improvement of pasta quality. In particular, the surface stickiness decreases and firmness improves, probably because the high-temperature drying system produces protein coagulation and the protein network, so formed, prevents starch granules from escaping during cooking.

The results of this study point out that SJ is determined by

TABLE VIII
Multiple Correlation Coefficients (*R*), Partial Regression Coefficients (*b*), and Relative Worths (*w*) of Two Viscoelastographic Parameters in Relation to Three Characteristics of Cooked Pasta Quality

	Stickiness			Bulkiness			Firmness		
	R	*b*	*w* (%)	*R*	*b*	*w* (%)	*R*	*b*	*w* (%)
50°C									
Consistency	0.47**[a]	0.58	. . .	0.48**	0.79	. . .	0.66**	2.26**	56
Relative recovery		27.37	. . .		−1.20	. . .		−70.24**	44
90°C									
Consistency	0.52**	1.03**	83	0.47**	1.17**	85	0.58**	1.47**	80
Relative recovery		23.56	17		−22.71	15		40.83	20

[a] $P = 0.05$ and 0.01 for * and **, respectively.

TABLE IX
Multiple Correlation Coefficients (*R*), Partial Regression Coefficients (*b*), and Relative Worths (*w*) of Two Viscoelastographic Parameters and Total Organic Matter in Relation to Sensory Judgment

	50°C			90°C		
	R	*b*	*w* (%)	*R*	*b*	*w* (%)
Consistency		−0.60	20		1.00**[a]	59
Relative recovery	0.95**	12.64	11	0.65**	5.22	3
Total organic matter		−20.98**	69		−8.68**	38

[a] $P = 0.01$ for **.

stickiness, bulkiness, and firmness in the ratio of 2:1:1 at 50°C and in the ratio of 1:1:1 at 90°C (Table V). Stickiness is well estimated by TOM, whereas firmness is better evaluated by viscoelastograph consistency.

Consequently, the combined effect of consistency, relative recovery, and TOM in determining SJ at low and high temperatures was investigated. Multiple regressions (Table IX) give evidence that TOM is a suitable method for estimating SJ at 50°C, whereas at 90°C it is more efficient to use TOM and viscoelastograph consistency jointly. At low temperature, in fact, stickiness is the most important SJ component (worth = 51%, Table V) and TOM is the most suitable measure of stickiness, whereas at high temperature the importance of surface characteristics decreases and firmness plays a more important role.

CONCLUSIONS

SJ, which evaluates jointly surface characteristics (stickiness and bulkiness) as well as firmness, can be considered the most comprehensive measure for cooking quality evaluation, but it is difficult to standardize this subjective method among different laboratories and countries.

This investigation on the objective methods useful to replace SJ demonstrates two points. 1) When a low-temperature drying system is applied, the TOM test is suitable for the evaluation of cooking quality because, in these conditions, surface characteristics are the most important. 2) When a high-temperature drying system is applied, viscoelastograph consistency can be usefully added to TOM test evaluation because firmness assumes a more important role in determining SJ.

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