Statistical Evaluation of Tests for Assessing Spaghetti-Making Quality of Durum Wheat[1]

R. R. MATSUO,[2] J. E. DEXTER,[2], F. G. KOSMOLAK,[2] and D. LEISLE[2]

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ABSTRACT

Thirty durum wheat cultivars grown at two locations for two years were subjected to detailed physical, chemical, and rheological tests to ascertain which test or group of tests best predicted spaghetti cooking quality. Data were pooled, and by analysis of variance, the influence of location, year, variety, and interactions on each quality test were determined. Simple correlation coefficients among all the tests were calculated to determine the interrelationship of the tests. Tests for gluten quality, farinograph bandwidth, and mixograph mixing time were significantly correlated to cooking quality. Stepwise regression analysis showed that semolina protein, specific absorption, sodium dodecyl sulfate sedimentation volume, and farinograph bandwidth are the best predictors of cooking quality. Specific absorbance appears to be the most useful test in which only one or two variables were used to predict cooking quality. Although spaghetti color values correlate to cooking quality characteristics, components or reactions causing brownness in spaghetti appear to be more important.

Important characteristics of durum wheats, in terms of pasta quality, are color and cooking quality. Color has not been a problem in variety development in North America, where durum cultivars have adequate yellow pigment and no brown discoloration. The emphasis in recent years has been on breeding for stronger gluten to improve rheological properties and cooking quality. According to Laignelet (1979), good cooking quality and high yellowness are incompatible; furthermore, brownness cannot be separated from good cooking quality. Cultivars released recently in Canada and the United States, however, prove that breeding can improve cooking quality without causing color to be sacrificed (Quick et al 1979).

A major problem in cultivar development is that no single test yet exists for predicting cooking quality of early generation material. The mixing characteristics, as determined on a micromixograph (Bendelow 1967), satisfactorily indicate gluten type (ie, strong, medium, or weak) but give a poor prediction of cooking quality (Dexter et al 1980).

Several reports have linked cooking quality to factors such as protein content (Dexter and Matsuo 1977a), gluten quality (Grzybowski and Donnelly 1977, 1979; Kosmolak et al 1980), gluten protein solubility (Dexter and Matsuo 1978b), ratio of glutenin to gliadin (Dexter and Matsuo 1977b, Wasik and Bushuk 1975), and farinograph mixing characteristics (Matsuo and Irvine 1970, Dexter and Matsuo 1980). Because spaghetti cooking quality depends on so many factors, making a reasonable prediction usually requires that several quality tests be performed.

This study was undertaken to determine which varietal and environmental influences affect cooking quality, which quality evaluation tests currently used in the Canadian durum wheat breeding program are related to pasta cooking quality, and which single test or group of tests best predict cooking quality.

In addition to tests normally associated with cooking quality, tests for evaluating color quality were included to determine whether pasta color properties could be related to textural characteristics.

MATERIALS AND METHODS

Plant Material

Of the 30 cultivars of durum wheat (*Triticum durum* Desf.) studied, 22 were developed in Canada (Stewart 63, Hercules, Wascana, Wakooma, Macoun, Coulter, and 16 cultivars from the Canadian breeding program), five were from the United States (Ramsey, Ward, Rolette, Cando, and Edmore), one was an Algerian durum (Pelissier), one was from Chile (Quilafen), and one was from France (64-47). All cultivars were grown at Glenlea, Manitoba, and at Swift Current, Saskatchewan, in 1978 and 1979.

Physical and Chemical Tests

Test weight was determined using a Schopper Chondrometer with a 1-L container; 1,000-kernel weight was determined by electronically counting 20 g of seed from which all broken kernels had been removed (Matsuo and Dexter 1980a). Protein content was determined by the Kjeldahl method (N × 5.7, 14.0% moisture basis) as modified by Williams (1973). Methods for determining ash and yellow pigment contents have been described by Dexter and Matsuo (1978a).

For the sodium dodecyl sulfate (SDS)-sedimentation test, 25 g of wheat was ground in a Udy Cyclone Mill, and the test was done according to the method of Axford et al (1978).

Semolina Milling

A 500-g sample of each cultivar from the two stations for each of the two years was tempered overnight to 16.5% moisture and milled by a three-stand Allis-Chalmers laboratory mill in conjunction with a laboratory purifier (Matsuo and Dexter 1980b).

Rheological Tests

Mixograph mixing time was calculated from micromixograph curves as described by Bendelow (1967). Farinograms were obtained by the method of Irvine et al (1961). All samples were mixed at 31.5% absorption. Mixing time is the time required to reach maximum consistency. Tolerance index is the decrease in consistency, measured in Brabender units, which occurs 4 min after the mixing time; bandwidth is measured at the same time. The farinograph score is calculated by dividing the product of bandwidth and mixing time by the tolerance index. The stronger the mixing characteristics of the dough, the greater is the farinograph score.

Protein Characterization

Gluten strength was determined on freshly washed-out gluten on an apparatus described by Matsuo (1978). Specific absorption was determined by dispersing semolina protein in aqueous urea, measuring the absorption at 280 nm, and dividing by the semolina protein content (Pomeranz 1965). The method of Orth and O'Brien (1976) was used for determining residue protein. Semolina was extracted with dilute acetic acid and centrifuged, and protein in the pellet (residue protein) was expressed as a percentage of total semolina protein.

Spaghetti Processing

Spaghetti was processed by the modified micromethod (Matsuo et al 1972). Processing absorption was varied, depending on the mixing characteristics of each sample. Samples were dried in a cabinet at 39° C with a stepwise decrease in relative humidity over 28 hr (Dexter et al 1981).

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[2]Research Station, Agriculture Canada, Winnipeg, Manitoba R3T 2M9.

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Spaghetti Cooking Quality

Textural characteristics of cooked spaghetti were evaluated on an apparatus described by Matsuo and Irvine (1969, 1971). Tenderness index is a measure of the shear rate under increasing force, compressibility is a measure of deformation under constant force, and recovery is a measure of the resilience. Normal cooking time for all spaghetti samples was 12 min; for assessing the tolerance to overcooking, cooking time was 22 min. A cooking quality indicator was derived from the ratio of the product of tenderness index and compressibility to recovery (Dexter and Matsuo 1977a).

Spaghetti Color

Spaghetti brownness was determined by measuring the absorption of an aqueous extract of semolina at 400 nm (Matsuo and Irvine 1967). Spaghetti color was determined by the Ten Selected Ordinates method (Hardy 1936). Brightness, purity, and dominant wavelength were determined on whole strands of spaghetti that were mounted on white cardboard by a Beckman DBG reflectance spectrophotometer (Dexter and Matsuo 1977b).

Precision of Tests

A representative sample of wheat was obtained to determine the standard deviation of each test. Results of repeating each test 10 times are presented in Table I.

RESULTS AND DISCUSSION

The mean values of each quality test for each year at the two locations are presented in Table II. The pooled mean and the standard deviation of the pooled data are also given. The large standard deviations for most tests reflect the qualitative diversity of the durum cultivars. All measurements were approximately normally distributed.

The contribution of year, location, and cultivar to the variance of each test, as calculated by the analysis of variance, is presented in Table III. If a test is to be of value in assessing spaghetti cooking quality, it should be influenced primarily by cultivar and not by year, location, or interactions involving cultivar. A significant interaction (Y × C or P × C) diminishes the value of the test.

Test weight, kernel weight, and milling yield are influenced primarily by year. Because conditions during the growing season generally dictate the soundness of the grain and because the soundness of the grain influences milling yield (Matsuo and Dexter 1980a), year is a dominant factor. Location is the principal source of variation for ash content and spaghetti brightness. This corroborates results of Feillet (1970), who also found a significant correlation between ash and location. Because brightness is influenced by ash content (Matsuo and Dexter 1980b) brightness also is largely influenced by location. Among the gluten-related tests, only residue protein was strongly influenced by location, and this limited the usefulness of the test as a predictor of quality.

Cultivar is significant in all of the tests, but only those for which the values are at least 50% should be considered to be of practical value. All tests for dough-mixing characteristics, gluten-related characteristics (except residue protein), and color values (except brightness) are influenced primarily by cultivar. Among the dough-mixing characteristics, bandwidth exhibited some significant interactions (Y × C and P × C). However, because more than 70% of variance in bandwidth can be attributed to cultivar, this test is still very useful. A highly significant interaction of location and cultivar (P × C) for specific absorbance may diminish the usefulness of this test as a predictor of cooking quality. All color values except brownness also exhibited a highly significant interaction of location and cultivar.

The influence of cultivar is not as dominant in the variability of cooking quality as it is in the variability of rheological or gluten properties. In samples cooked for normal time, year is the principal source of variation in compressibility and tenderness. This might be because soundness of wheat (ie, freedom from environmental damage or damage from microorganisms) and protein content are dependent on the growing conditions of the year. This point is an important one to consider in a breeding program. As Damidaux (1979) recently noted, a given screening test may in fact be an ideal breeding tool for predicting which lines have a higher potential for cooking quality but still may not be well correlated with the actual cooking quality of a given sample, depending on the growing conditions.

TABLE I
Means and Standard Deviations of Each Quality Test Based on 10 Single Determinations on a Representative Sample

Quality Test	Code	Unit	Mean	Standard Deviation	Coefficient of Variation
Test weight	TeW	kg/hL	83.24	0.11	0.13
1,000 kernel weight	TKW	g	50.14	0.96	1.91
Wheat ash	WhA	%	1.464	0.012	0.82
Wheat protein	WhPr	%	14.68	0.16	1.09
Milling yield	MiY	%	69.62	0.42	0.60
Semolina ash	SeA	%	0.644	0.010	1.55
Semolina protein	SePr	%	11.90	0.08	0.67
Mixograph mixing time	MMT	min	1.61	0.01	0.61
Farinograph mixing time	FMT	min	5.75	0.29	5.04
Farinograph tolerance index	FTI	BU	47.0	4.83	1.02
Farinograph bandwidth	FBW	BU	86.5	4.74	5.48
Farinograph score	FSc	min	10.70	1.43	13.36
Sodium dodecyl sulfate sedimentation volume	SDS	mL	45.20	1.11	2.45
Gluten strength	GlS	N	1.249	0.053	4.24
Residue protein	Res	%	32.61	0.44	1.35
Specific absorbance	SAb	OD280/SePr	55.45	1.65	2.97
Compressibility	C	%	67.2	3.5	5.21
Recovery	R	%	45.3	2.9	6.40
Tenderness index	T	$mm/sec \times 10^3$	45.3	1.4	3.09
Cooking quality	CQ	$sec/mm \times 10^{-3}$	15.1	1.9	12.58
Wheat pigment	WhP	ppm	7.56	0.084	1.11
Semolina pigment	SeP	ppm	5.23	0.076	1.45
Spaghetti pigment	SpP	ppm	3.61	0.111	3.07
Spaghetti brownness	SpB	o.d. 400	0.297	0.025	8.42
Pigment loss	PLS	%	30.88	2.50	8.09
Brightness	Bri	%	41.16	0.13	0.32
Purity	Pur	%	62.30	0.40	0.64
Dominant wavelength	DWL	nm	578.21	0.11	0.02

Simple correlation coefficients were calculated among all the quality measurements for each year and for each location. Tests of homogeneity of the correlation coefficients (Steel and Torrie 1960) showed several heterogeneous correlations. Data showing homogeneity were pooled (Fig. 1). Values of r (× 100) of 18 or greater are significantly different from zero at $P = 0.05$, and values of 23 or greater are signficantly different from zero at $P = 0.01$.

Highly significant correlation coefficients are scattered throughout the matrix. Some of them are obvious, such as those among farinograph characteristics, among cooking quality parameters, and among color parameters. Others might be more or less fortuitous. For example, the significant correlations of kernel weight with pigment content and purity are difficult to explain. Correlations of test weight to cooking quality might be explained on the basis of soundness of wheat. In sound wheat, test weight is usually inversely related to total protein content (Fig. 1). Although the data in Fig. 1 indicate that protein content does not significantly affect gluten strength, they confirm the previous report that protein content is significant in cooking quality (Dexter and Matsuo 1977a). This, in turn, might lead to the observed correlation between test weight and cooking quality.

The significant correlation of color to cooking quality might be attributable to the large number of cultivars from the Canadian breeding program within our sample population. Almost all of the Canadian cultivars have high yellow pigment content, medium to medium-strong gluten characteristics, and fairly good cooking quality. If more North American durum varieties with weak gluten characteristics, high yellow pigment content, and mediocre cooking quality had been included in the study, this relationship may not have been significant. That brownness is not highly correlated to cooking quality might be explained by the fact that Pelissier is the only cultivar among the 30 studied that has a distinct brownish discoloration. The brownness test used in this study measures brownness in semolina and not in the processed product and is analogous to the brown index of semolina (BIS) defined by Kobrehel et al (1974).

If a brownish discoloration develops during processing, it may be attributable to the "potential brown index of semolina (PBIS)" (Kobrehel et al 1974) resulting from peroxidase activity or to what Laignelet (1979) ascribes to "oxydoreduction reactions." Because dominant wavelength (DWL) is determined on the processed product and because an increase in DWL indicates a degree of browning, DWL should be related to PBIS. The high correlation of PBIS to protein content (Kobrehel et al 1974) may explain the significant correlation between DWL and cooking quality (CQ 12 and CQ 22).

Many of the correlations among protein quality and quantity to cooking quality corroborate previous findings. For example, cooking quality reportedly has been related to protein content (Dexter and Matsuo 1977a), to farinograph characteristics (Matsuo and Irvine 1970), to SDS-sedimentation volume, mixograph characteristics, and to gluten strength (Dexter et al 1980).

Tests related to gluten quality—SDS-sedimentation volume, gluten strength, residue proteins, and specific absorbance—show significant correlations to cooking quality, except for tenderness index cooked for normal time. Tenderness index, a measure of the shear rate, does not necessarily reflect the resilience of the cooked sample. Feillet et al (1977) claimed that cooked pasta resilience is largely governed by gluten characteristics. Using their "viscoelastograph," they demonstrated that strong gluten varieties with high elastic recovery all exhibited good cooking quality, whereas weak gluten varieties with low elastic recovery had poorer cooking quality.

In contrast to cooked pasta resilience, tenderness index at normal cooking time may well be a measure of textural characteristics strongly influenced by gelatinized starch and not by gluten characteristics. In overcooked samples, in which tenderness index correlates significantly to three of four gluten tests, starch gel structure may break down, in which case the residual structural

TABLE II
Mean of Each Quality Test for Each Site-Year and for Pooled Data and Standard Deviation of Pooled Data

Test	Glenlea 1978	Glenlea 1979	Swift Current 1978	Swift Current 1979	Pooled Mean	Standard[a] Deviation
Test weight	77.53	82.99	81.33	83.53	81.35	2.84
1,000 kernel weight	42.21	49.32	34.80	43.51	42.46	6.15
Wheat ash	1.83	1.84	1.34	1.44	1.64	0.24
Wheat protein	15.35	14.40	14.14	13.82	14.43	1.02
Milling yield	68.07	70.75	66.24	69.64	68.68	2.09
Semolina ash	0.78	0.77	0.66	0.69	0.72	0.07
Semolina protein	14.61	13.68	13.47	13.21	13.74	1.02
Mixograph mixing time	1.70	1.75	1.69	1.70	1.71	0.30
Farinograph mixing time	4.12	4.73	4.10	4.32	4.32	1.02
Farinograph tolerance index	125.67	97.83	98.67	90.67	103.21	36.25
Farinograph bandwidth	88.00	95.67	77.33	81.33	85.58	29.05
Farinograph score	3.70	6.29	4.56	4.85	4.85	3.65
Sodium dodecyl sulfate sedimentation volume	30.55	23.61	37.98	32.15	31.07	8.93
Gluten strength	0.99	0.78	0.90	0.71	0.85	0.38
Residue protein	39.62	34.88	30.25	32.62	34.34	4.54
Specific absorbance	57.22	63.23	61.21	60.27	60.48	13.80
Compressibility (12 min)	61.73	75.60	67.33	75.77	70.11	7.97
Recovery (12 min)	60.37	45.33	48.60	39.83	48.53	12.59
Tenderness index (12 min)	40.53	35.67	43.30	34.97	38.62	4.85
Cooking quality (12 min)	25.40	17.47	17.20	15.77	18.96	6.90
Compressibility (22 min)	57.67	79.33	66.67	74.67	69.58	14.24
Recovery (22 min)	64.57	37.07	52.60	47.03	50.32	21.28
Tenderness index (22 min)	46.67	46.00	48.53	41.17	45.59	4.99
Cooking quality (22 min)	26.80	11.73	17.87	16.17	18.14	9.34
Wheat pigment	8.21	7.57	8.41	7.80	8.00	1.25
Semolina pigment	6.59	5.93	7.17	6.82	6.63	1.41
Spaghetti pigment	5.08	4.37	6.04	5.42	5.23	1.22
Spaghetti brownness	0.22	0.20	0.20	0.15	0.19	0.06
Pigment loss	23.11	26.18	28.60	20.40	24.57	6.85
Brightness	40.65	41.18	45.29	45.85	43.24	2.84
Purity	59.46	57.02	62.98	60.61	60.02	4.32
Dominant wavelength	578.63	578.34	578.14	578.06	578.29	0.41

[a]Values for standard deviation are calculated for n = 120 (30 varieties, two stations, two years).

TABLE III
Percentage of the Total Sum of Squares from the Analysis of Variance Attributable to Each Source of Variation for Each Quality Test

Test	Source of Variation						
	Year (Y)	Place (P)	Cultivar (C)	Y × P	Y × C	P × C	Y × P × C[a]
Test weight	46.1[b]	14.8[b]	14.6[b]	8.4[b]	3.3	9.0[c]	3.9
1,000 kernel weight	41.7[b]	29.1[b]	17.7[b]	0.4[c]	3.9	4.5	2.6
Wheat ash	1.2[b]	87.7[b]	5.2[b]	0.7[b]	1.6	2.4[c]	1.2
Wheat protein	9.7[b]	19.3[b]	31.8[b]	2.4[c]	11.6	13.5	11.6
Milling yield	53.2[b]	12.4[b]	12.6[c]	0.7	5.4	10.0	5.7
Semolina ash	0.3	57.7[b]	22.1[b]	1.8[b]	5.4	8.8[c]	3.9
Semolina protein	8.5[b]	15.8[b]	33.2[b]	2.7[c]	14.3	14.9	10.5
Mixograph mixing time	0.3	0.2	77.2[b]	0.1	7.1	8.4	6.7
Farinograph mixing time	4.2[b]	1.2[b]	79.7[b]	0.9[c]	3.8	6.2	4.0
Farinograph tolerance index	6.2[b]	5.6[b]	69.8[b]	1.9[b]	3.2	7.1	6.3
Farinograph bandwidth	1.0[c]	4.7[b]	72.6[b]	0.1	9.4[c]	8.0[c]	4.2
Farinograph score	4.0[b]	0.2	67.9[b]	2.5[c]	4.8	7.8	12.9
Sodium dodecyl sulfate sedimentation volume	12.9[b]	20.2[b]	61.7[b]	0.1	2.6[c]	1.4	1.1
Gluten strength	6.7[b]	1.0[b]	79.7[b]	0.0	4.7	4.7	3.2
Residue protein	1.7[b]	41.3[b]	28.7[b]	15.5[b]	3.2	4.1	5.5
Specific absorbance	11.2[b]	0.5	49.7[b]	21.1[b]	5.4	8.7[b]	3.4
Compressibility (12 min)	49.3[b]	3.3[b]	29.6[b]	2.9[b]	2.7	3.8	8.4
Recovery (12 min)	22.5[b]	11.9[b]	45.1[b]	1.6[c]	3.4	6.0	9.5
Tenderness index (12 min)	46.7[b]	1.1[c]	27.7[b]	3.2[b]	8.7	6.1	6.4
Cooking quality (12 min)	10.6[b]	12.3[b]	49.3[b]	5.1[c]	4.3	10.3	8.2
Compressibility (22 min)	27.4[b]	0.6	47.8[b]	5.8[b]	4.3	9.9[c]	4.2
Recovery (22 min)	15.2[b]	0.1	57.5[b]	6.7[b]	4.7	10.5[c]	5.4
Tenderness index (22 min)	16.3[c]	2.2[b]	48.1[b]	11.4[b]	7.5[c]	10.4[b]	3.9
Cooking quality (22 min)	17.8[b]	1.1[b]	49.7[b]	12.4[b]	5.3	9.6[c]	4.1
Wheat pigment	6.3[b]	0.7[b]	85.3[b]	0.0	2.1	4.2[b]	1.3
Semolina pigment	3.2[b]	6.9[b]	85.6[b]	0.3[b]	0.9	2.3[b]	0.9
Spaghetti pigment	7.5[b]	17.3[b]	68.8[b]	0.0	2.1	3.2[b]	1.1
Spaghetti brownness	5.8[b]	6.8[b]	71.5[b]	1.1[c]	3.2	2.6	5.7
Pigment loss	3.5[b]	0.0	55.9[b]	17.1[b]	10.4[b]	9.9[b]	3.2
Brightness	0.9[b]	67.7[b]	15.7[b]	0.0	3.5	8.9[b]	3.3
Purity	7.8[b]	17.0[b]	67.9[b]	0.0	2.8	2.8[b]	1.7
Dominant wavelength	5.0[b]	21.9[b]	46.5[b]	1.5[b]	3.2	16.5[b]	5.4

[a] Interaction Y × P × C used as the residual term.
[b] Significantly different from zero at $P = 0.01$.
[c] Significantly different from zero at $P = 0.05$.

TABLE IV
Results of Stepwise Regression in the Prediction of the Six Cooking Quality Variables

Dependent Variable	Step	r^2 (× 100)	Variables			
			1	2	3	4
Compressibility						
(12 min)	1	33.8	Specific absorbance			
	2	42.9	Specific absorbance	Semolina protein		
	5	57.1	Semolina protein	Sodium dodecyl sulfate (SDS) sedimentation	Gluten strength	
(22 min)	1	42.6	Specific absorbance			
	2	46.8	Specific absorbance	SDS sedimentation		
	5	59.2	Residue	SDS sedimentation	Semolina protein	
Recovery						
(12 min)	1	31.7	Semolina protein			
	2	59.2	Semolina protein	Gluten strength		
	3	62.2	Semolina protein	Gluten strength	Bandwidth	
	4	63.5	Semolina protein	Gluten strength	Bandwidth	SDS sedimentation
(22 min)	1	38.8	Specific absorbance			
	2	44.1	Specific absorbance	Bandwidth		
	3	47.1	Specific absorbance	Bandwidth	Farinograph (Far.) mix time	
	6	53.2	Specific absorbance	Bandwidth	SDS sedimentation	Semolina protein
Tenderness index						
(12 min)	1	20.5	Bandwidth			
	2	26.6	Bandwidth	SDS sedimentation		
	3	31.4	Bandwidth	SDS sedimentation	Far. tolerance index	
	4	39.8	Bandwidth	SDS sedimentation	Far. tolerance index	Semolina protein
(22 min)	1	20.0	Bandwidth			
	4	36.5	Semolina protein	Far. tolerance index		

integrity would be influenced mostly by gluten characteristics. This hypothesis is supported by a recent study of cooked spaghetti with a scanning electron microscope (Dexter et al 1978).

In agreement with a recent report (Dexter and Matsuo 1980), farinograph bandwidth was the dough-mixing characteristic that exhibited the strongest correlation to cooking quality. Bandwidth is related to dough stickiness (Matsuo and Irvine 1975) and represents shear force at a particular stage of dough development. Its association with gluten strength is evidenced by a highly significant correlation coefficient with gluten breaking strength.

Differences in correlation coefficients for mixograph and farinograph mixing times with cooking quality likely can be attributed to the difference in dough absorption. True dough development might not be attained until about 45% absorption is reached in a farinograph (Dexter and Matsuo 1979). Mixing time has been previously shown to decrease with increasing absorption

	TEST WEIGHT	1000 KERNEL WEIGHT	WHEAT ASH	WHEAT PROTEIN	MILLING YIELD	SEMOLINA ASH	SEMOLINA PROTEIN	MIXOGRAPH MIX TIME	FARINOGRAPH MIX TIME	FARINOGRAPH TOL. INDEX	FARINOGRAPH BAND WIDTH	FARINOGRAPH SCORE	SDS-SEDIMENTATION VOLUME	GLUTEN STRENGTH	RESIDUE	SPECIFIC ABSORBANCE	COMPRESSIBILITY -12	RECOVERY-12	TENDERNESS INDEX-12	COOKING QUALITY-12	COMPRESSIBILITY-22	RECOVERY-22	TENDERNESS INDEX-22	COOKING QUALITY-22	WHEAT PIGMENT	SEMOLINA PIGMENT	SPAGHETTI PIGMENT	SPAGHETTI BROWNNESS	PIGMENT LOSS	BRIGHTNESS	PURITY	DOMINANT WAVELENGTH
DWL	-63	ns	51	34	ns	H+	32	21	26	ns	39	ns	-18	40	55	-29	-51	61	H-	61	-52	49	-19	54	38	25	H+	H+	H-	-78	H+	100
Pur	ns	-49	-43	ns	-48	-48	ns	ns	ns	-23	31	ns	69	42	-19	-38	-41	34	ns	-32	-52	52	-32	48	79	88	97	ns	H-	H+	100	
Bri	54	H-	-82	-49	ns	-80	-46	ns	ns	ns	-27	ns	22	-22	-62	ns	33	H-	H+	H-	26	-22	H+	-28	H-	ns	H+	-50	ns	100		
PLs	ns	ns	ns	ns	ns	ns	ns	-24	ns	ns	ns	ns	-19	-23	H-	41	ns	ns	25	ns	H+	ns	26	-21	H+	ns	H-	36	100			
SpB	H-	H-	H+	ns	H-	H+	ns	ns	ns	ns	ns	21	ns	ns	22	ns	-29	33	ns	28	ns	ns	ns	ns	ns	ns	ns	100				
SpP	H-	-49	-44	ns	-46	-47	ns	ns	ns	-22	30	ns	68	39	ns	-35	-39	32	ns	31	-50	50	-32	47	84	93	100					
SeP	ns	-39	-27	ns	-37	-32	ns	ns	ns	-24	39	ns	56	34	ns	-26	-36	35	ns	35	-48	49	-40	46	96	100						
WhP	-26	-36	ns	ns	-39	ns	ns	ns	ns	ns	40	ns	45	30	ns	H-	-44	45	ns	43	-51	49	-32	49	100							
CQ22	-62	-22	ns	47	-38	21	44	-27	ns	ns	42	ns	51	52	41	-68	-82	82	H-	83	-95	94	H-	100								
T22	ns	ns	ns	ns	ns	ns	ns	-27	-30	43	-44	-26	-32	-29	ns	33	ns	-30	77	-46	H+	-49	100									
R22	-52	-24	ns	36	-38	ns	33	32	20	-19	43	ns	54	53	33	-62	-77	77	H-	73	-97	100										
C22	62	30	ns	-42	47	ns	-38	-29	ns	ns	-40	ns	-54	-53	-36	65	83	-81	H+	-76	100											
CQ12	-64	ns	36	61	-26	39	58	26	ns	ns	48	ns	32	49	43	-58	-84	94	H-	100												
T12	-24	-51	-21	ns	-42	-20	ns	-23	-36	38	-45	-33	ns	ns	ns	H-	H-	H-	100													
R12	-70	ns	-34	60	-37	36	56	24	ns	ns	42	ns	35	48	38	-56	-92	100														
C12	76	36	ns	-52	55	-18	-50	ns	ns	ns	-27	ns	-44	-48	-32	58	100															
SAb	47	ns	ns	-42	H+	ns	-38	-40	-25	ns	-35	ns	-58	-58	-45	100																
Res	-47	30	64	22	ns	61	ns	38	41	ns	38	29	ns	48	100																	
GlS	-35	ns	ns	ns	-29	ns	ns	73	63	-54	63	55	70	100																		
SDS	-19	-53	-47	ns	-57	-46	ns	53	42	-48	46	34	100																			
FSc	ns	ns	ns	-38	ns	ns	-41	60	84	-79	73	100																				
FBW	ns	ns	21	ns	ns	ns	ns	56	75	H-	100																					
FTI	-19	ns	20	52	ns	ns	55	-54	-69	100																						
FMT	ns	22	ns	-35	ns	ns	-40	66	100																							
MMT	ns	ns	ns	-22	ns	ns	-27	100																								
SePr	-53	H+	43	98	ns	48	100																									
SeA	-45	41	87	48	27	100																										
MiY	53	80	38	ns	100																											
WhPr	-54	ns	44	100																												
WhA	-38	52	100																													
TKW	H+	100																														
Tew	100																															

n = 120

Fig. 1. Correlation matrix for 32 durum wheat quality characteristics (r × 100). **ns** = not significant. **H** = heterogeneous, **r** ≥ 18 significantly different from zero at 5% probability, **r** ≥ 23 significantly different from zero at 1% probability.

to a minimum and then increase for all durum wheat cultivars studied. The mixograph mixing time is obtained for doughs mixed at 50% absorption. Mixing properties at low absorption (eg, farinograph doughs at 31.5% absorption) are useful for predicting extrusion properties, but rheological properties at higher absorption where gluten is fully developed may better predict the textural characteristics of cooked spaghetti.

Further regression analyses were run to determine which variable or groups of variables best predicted each of six cooking quality components (tenderness index, compressibility, and recovery for samples cooked 12 and 22 min). Stepwise regression was run for each of the six variables using 10 noncolor and independent variables (semolina protein, mixograph mixing time, four farinograph parameters, SDS-sedimentation volume, gluten strength, residue, and specific absorbance). The stepwise regression procedure is a forward inclusion with a backward elimination (ie, variables are entered one at a time and deleted if they become redundant). A step is defined as the inclusion or deletion of a variable until no more variables can be entered or deleted.

Results of the stepwise regression analysis are given in Table IV. In no case were more than four variables entered, but in some cases, only two or three were included. Interestingly, semolina protein occurs in all six cooking parameters, SDS-sedimentation volume in five of six, and farinograph bandwidth in four of six.

The lower coefficient of determination values (r^2) for tenderness indexes (12 and 22 min) suggests that other tests should be included as independent variables. Development of screening tests related to characterizing starch properties may prove to be of some benefit.

Scaracia-Venezian (1973) reported that accessible sulfhydryl and urea-dispersible proteins (specific absorbance) appeared to be the best indicators of pasta-making quality. The role of sulfhydryl is not clear, because Dexter and Matsuo (1977c) were unable to establish any relationship between spaghetti cooking quality and sulfhydryl levels. Results of the current study, however, show that specific absorbance is a very prominant variable in the prediction of recovery and compressibility.

Previously, specific absorbance was shown to correlate highly to bread-making potentialities of wheat (Pomeranz 1965). The ease with which wheat proteins are dispersed and disaggregated in urea might be related to the structural breakdown of the protein network during mechanical or heat processing of dough during breadmaking. In pasta doughs, as well, a compact protein structure with inaccessible hydrogen bonds (thus, being less dispersible in urea) could result in formation of a more stable protein network during pasta processing. This could lead to a structure with desirable textural characteristics in cooked spaghetti.

All of the variables considered in the stepwise regression are related to protein. Specific absorbance, SDS-sedimentation volume, farinograph bandwidth, and protein content, the variables that occurred most often in the stepwise regression, can account for only about 60% of the variability in three of the six cooking parameters. No combination of variables was found that would predict even 40% of the variability in tenderness index. These results show that although protein content and quality are definite prerequisites for superior cooking quality, other factors are also involved. An urgent need exists for research to identify these other factors and to develop new testing procedures to complement those currently in use.

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