PHYSICAL, SENSORY AND CHEMICAL EVALUATION OF COOKED SPAGHETTI

CRISTINA S. MARTINEZ[1], PABLO D. RIBOTTA[1,2], ALBERTO E. LEÓN[1,2,4] and
M. CRISTINA AÑÓN[3]

[1]*Facultad de Ciencias Agropecuarias*
Universidad Nacional de Córdoba
CC 509, 5000, Córdoba, Argentina

[2]*Unidad Ceprocor*
Agencia Córdoba Ciencia SE
5164, Santa María de Punilla, Córdoba, Argentina

[3]*Centro de Investigación y Desarrollo en Criotecnología de Alimentos*
(CONICET-UNLP)
CC 553, La Plata (1900), Argentina

ABSTRACT

The objectives of this research were to estimate the ability of chemical analysis, cooking properties, sensory evaluation and instrumental texture assays as descriptive quality parameters, and to evaluate the association between sensory and instrumental measurements on commercial pasta samples. Five commercial samples, Com1 to Com5, were analyzed. Moisture, protein and ash contents were determined from raw materials, while cooking loss, water absorption and leached amylose were measured in cooked samples. Color parameters (L*, a* and b*) were determined spectrophotometrically and color scores were calculated from raw and cooked samples. Three instrumental texture assays by a texture analyzer (TA-xT2i) and seven sensory parameters were evaluated. Chemical analysis, cooking properties, sensory evaluation and texture measurement were found to be sensitive quality parameters. From the analysis of the results, Com1 showed the best quality. A significant relationship between the sensory and instrumental measurements according to Pearson correlation and the principal component analysis was also observed.

[4] Corresponding author. TEL: +54-351-4334103 + 255; FAX: +54-351-4334118; EMAIL: aeleon@agro.uncor.edu

PRACTICAL APPLICATIONS

In this work, the quality of different commercial pastas was assessed by means of chemical analysis, cooking properties, sensory evaluation and instrumental texture. The goal of this study was to identify the most important determinations related to pasta quality, and it allowed the establishment of the relationship between the sensory properties and texture measurements.

KEYWORDS

Cooking properties, pasta quality, sensory evaluation, texture

INTRODUCTION

Pasta is a traditional food product whose origins date back to the first century BC, and it is favored by consumers for its ease of transportation, handling, cooking and storage properties (Tudoricá *et al*. 2002). Economics also plays an important role as food based on noodles can easily be afforded by people in the low-income bracket. Moreover, a dish of pasta can be a complete and nutritious meal (Virtucio 2003). Durum wheat (*Triticum turgidum* L. var. *durum*) is the cereal of choice for pasta production because of its unique color, flavor and cooking quality (Feillet and Dexter 1996); however, many spaghetti products are prepared from *Triticum aestivum* L.

The characteristics of pasta products, such as color, cooking properties, texture and taste, are important factors affecting consumer acceptance and product quality (Lee *et al*. 2002). Dry pasta must appeal to the consumer at the point of purchase and the cooked pasta should have "al dente" quality and must meet consumer criteria for good yellow color retention, smooth surface, firmness and resilience; it must tolerate moderate overcooking, has minimal cooking loss and offer a pleasing flavor (Sissons *et al*. 2005).

Although sensory evaluation still remains the most reliable test to assess pasta quality, many objective methods have been developed in order to achieve simplicity and to avoid subjectivity inherent in the sensory process. Concurrently, among instrumental methods, it is necessary to evaluate their ability to describe pasta quality. The objectives of this research were to estimate the ability of chemical analysis, cooking properties, sensory evaluation and instrumental texture analysis as descriptive quality parameters, and to evaluate the association between sensory and instrumental measurements.

MATERIALS AND METHODS

Samples

Five commercial wheat spaghetti were purchased in a local supermarket (Córdoba, Argentina). Samples were named Com1, Com2, Com3, Com4 and Com5. Com1 was made from semolina durum wheat, and Com2 to Com5 were made from wheat flour. Five hundred grams of each sample were stored at room temperature in a sealed bag. Sample labeling information were semolina of durum wheat for Com1 and bread wheat flour, fortified with Fe, niacin, thiamine, folic acid, riboflavin, semolina and curcuma dye, for Com2 to Com5.

Chemical Analysis

Ground spaghetti samples were sieved through a 1-mm screen. Moisture content was determined by drying at 130C for 2 h; the protein content was determined by the Kjeldhal method ($N \times 5.7$) and the ash content was determined at 590C; all analyses were performed in duplicate according to approved methods 44.15 A, 46-30 and 08-01, respectively (AACC 1995).

Determination of Cooking Properties

Spaghetti was cooked in boiling distilled water.

Optimal Cooking Time. The "al dente" point was determined by compressing the spaghetti strand between two glass slides in 30-s intervals. The optimal cooking point was reached when the white center of ungelatinized starch had just disappeared according to the approved method 16-50 cooking time (AACC 1995).

Cooking Loss. Cooking water collected from each sample was evaporated until constant weight in an air oven at 105C. The residue was weighted and reported as percentage of original spaghetti sample according to approved methods 16-50 cooking loss (AACC 1995).

Water Absorption. Water absorption of drained spaghetti was determined as [(weight of cooked pasta − weight of raw pasta)/weight of raw pasta] × 100. Twelve and a half grams of spaghetti samples were cut into pieces 5-cm long; they were cooked until their optimal cooking time was reached in 200-mL boiling distilled water, and afterwards, drained and rinsed with another 50 mL of distilled water at room temperature for 1 min; they were weighted after reaching room temperature.

Amylose Content in Cooking Water. Cooking and rinsed water were collected in a volumetric flask that was filled with distilled water up to 300 mL. Amylose content was determined according to Funami *et al.* (2005). An aliquot from each sample was mixed with an equal volume of 0.33 M NaOH, and immersed in a boiling water bath for 20 min for complete gelatinization. After reaching room temperature, a 50-μL aliquot of the suspension was diluted (1:2) with distilled water and mixed with 50 μL of 0.33 M NaOH; then, 1-mL 1% TCA, and finally, 50 μL of Lugol reactive (I_2 0.2% + KI 2%) were added. After 20 min at room temperature, amylose was determined spectrophotometrically at 620 nm against a water blank prepared in the same conditions. The amylose content was quantified through linear regression analysis using 0.7, 1.6, 3.2 and 6.3 mg % amylose standard solutions (A-7043, Sigma-Aldrich, St. Louis, MO). The amylose content was measured by duplicate on two different days, totaling to four measurements for each sample.

Color of Raw and Cooked Spaghetti

Spaghetti color was determined with a Minolta 508d spectrophotometer (Ramsey, NJ). An eight-millimeter measurement aperture, D65 illuminant, 10° angle of observer according to approved methods 14-22 (AACC 1995) were set. Raw and cooked strands of spaghetti were laid in parallel to cover an area about 5-cm wide on a black background (~0% reflectance). At least eight readings were taken from the raw and cooked spaghetti strand and recorded as CIE-LAB, *L** (lightness), *a** (redness-greenness) and *b** (yellowness-blueness) values.

Sensory Evaluation

Sensory profiling was performed by a nontrained descriptive panel; the staff consisted of 13 individuals (six males and seven females) from Laboratorio de Química Biológica, Facultad de Ciencias Agropecuarias de la Universidad Nacional de Córdoba, using a generic descriptive analysis technique, in agreement with Tang *et al.* (1999). The descriptor definitions of sensory attributes are shown in Table 1.

All samples were presented to each judge at the same time. The order of sample presentation was completely randomized among judges, identified with three random numbers. Cooked spaghetti was presented in 250-mL sealed thermal plastic cups and served at room temperature within 1 h after cooking. All attributes were evaluated either orally or manually under daylight. Discontinuous bipolar 7-point scales were used, where 1 represented low intensity and 7 represented high intensity in a particular attribute. Drinking water was provided for palate cleansing between each sample (Tang *et al.* 1999).

TABLE 1.
DEFINITION OF THE SENSORY ATTRIBUTES (TANG *ET AL.* 1999)

Appearance evaluated in daylight by visual observation	
Yellow color	The intensity of the yellow color of spaghetti surfaces.
Shininess	The extent to which the light reflects on the spaghetti surface.
Surface smoothness	The size of pinholes on spaghetti surfaces.
Texture evaluated in daylight by manipulating the samples in the mouth	
Firmness	The force required to cut through the spaghetti using the front teeth.
Chewiness	The length of time required to masticate the spaghetti to a state of swallowing.
Texture evaluated in daylight by manipulating the samples using the hands	
Surface stickiness	The extent to which two pieces of spaghetti stick together when separated.
Elasticity	The extent to which a piece of spaghetti returns to its original length when stretched.

Cooked Spaghetti Textural Analysis

A texture analyzer (TA-xT2i, Stable Micro Systems, Godalming, U.K.) equipped with a Windows version of the Texture Expert Software package was used to make three different texture analyses: (1) spaghetti firmness at optimal cooking time and at overcooking; (2) spaghetti hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience; and (3) spaghetti stickiness. For all measurements, TA-XT2i was equipped with a 25-kg load cell. All samples were prepared and kept until measurement according to the approved method 16-50 pasta cooking quality – firmness (AACC 1995).

To determine the firmness at optimal cooking time and overcooking time, 5-cm length strands were oriented perpendicularly to the Warner–Bratzler shear blade (type HDP/BS), on a flat aluminum platform base, in such a way that each spaghetti strand was in contact with the next. The probe compressed the spaghetti samples at a rate of 0.17 mm/s to 70% strain, and it was retracted to end the test. Firmness was measured as the maximum peak force of curve. The test was repeated on two samples prepared on different occasions, five times on each occasion, on two different places of the sample surface.

For the second test, spaghetti strands were oriented for TPA as described above, but in this case, an HDP/PFS pasta firmness–stickiness probe was fixed to the texturometer. Before testing the samples, excess water was blotted with an absorbent paper. The probe compressed the spaghetti samples at a rate of 2.0 mm/s to 70% strain. The probe was retracted and followed by a second compression cycle after 2 s. The variables (hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience) were recorded through five measurements for each sample, on two samples prepared in different occasions, totaling to 10 measurements. Spaghetti hardness was defined as the peak force attained during the first compression. Adhesiveness was defined as the

negative area under the first compression, representing the work necessary to pull the compressing plunger away from the sample. Springiness was defined as the rate at which a deformed sample went back to its undeformed condition after the deforming force is removed, calculated as the ratio of distance of the first half of the second peak to the distance of the first half of the first peak. Cohesiveness was defined as the ratio of the area under the second peak to the area under the first peak. Chewiness was defined as the product of hardness, cohesiveness and springiness. Resilience was defined as the ratio of area under the second half of the first peak to the area under the first half of the same peak.

For the spaghetti stickiness assay, samples were prepared, conditioned and oriented on the texturometer plate as described above. The probe HDP/ PFS pasta firmness–stickiness descended through the sample at a speed of 0.5 mm/s until it reached a force of 49.03 N, held stationary for 3 s and retracted to end the test. Stickiness was defined as the maximum peak force to separate the probe from the sample surface upon probe retraction (the higher the force value, the stickier the sample) (Stable Micro Systems 1995). The test was repeated five times for each sample, on two samples prepared on different occasions, totaling to 10 measurements.

All values were calculated for initial contact area between the sample and probe of 1 cm^2.

Statistical Analysis

Results were expressed as the mean of replications $\pm$ SD. The data were compared by the test of Fisher, with significant level at 0.05. Principal component analysis (PCA) was carried out for color values, sensory evaluation and texture analysis to investigate the within-set data profile and to study the correlation between the instrumental and sensory data. Pearson correlation coefficients were also calculated as a measure of that association. All analyses were made using the Info Stat Statistical Software (Facultad de Ciencias Agropecuarias, UNC, Argentina).

RESULTS AND DISCUSSION

Chemical Analysis

The results obtained for all samples are shown in Table 2. The spaghetti samples had similar moisture contents from 10.5 to 11.0%, except for Com3, which was at 12.5%. The total protein content of samples varied from 10.0 to 11.1%; only Com2 was significantly different, showing the lowest value of 10.0%. The ash content presented a wide range varying from 0.54 to 0.71% from Com2 to Com5, which were all bread wheat flour samples, and also

TABLE 2.
MOISTURE, PROTEIN AND ASH CONTENT OF
PASTA SAMPLES

Sample	Moisture (%)	Protein (%)	Ash (%)
Com1	10.7 ± 0.0 b	11.1 ± 0.0 b	0.98 ± 0.02 e
Com2	11.0 ± 0.1 c	10.0 ± 0.3 a	0.54 ± 0.00 a
Com3	12.5 ± 0.0 d	11.0 ± 0.3 b	0.59 ± 0.01 b
Com4	10.5 ± 0.0 a	10.8 ± 0.1 b	0.65 ± 0.00 c
Com5	10.8 ± 0.1 b	11.0 ± 0.0 b	0.71 ± 0.01 d

Values followed by a different letter are significantly different
($P < 0.05$).
Results were expressed as the mean of replications ± SD.

TABLE 3.
COOKING PROPERTIES OF PASTA SAMPLES

Sample	OCT (min)	Cooking loss (%)	Water absorption (%)	Amylose (%)
Com1	10.5	5.3 ± 0.0 b	266 ± 1 c	2.0 ± 0.2 a
Com2	8.5	4.4 ± 0.0 a	256 ± 1 ab	2.2 ± 0.2 a
Com3	9.5	4.5 ± 0.0 ab	254 ± 3 a	2.5 ± 0.2 b
Com4	7.5	6.4 ± 0.7 c	259 ± 0 b	4.7 ± 0.2 d
Com5	7.5	6.3 ± 0.3 c	267 ± 0 c	3.7 ± 0.1 c

Values followed by a different letter are significantly different ($P < 0.05$).
Results were expressed as the mean of replications ± SD.
OCT, optimal cooking time.

0.98% for Com1, the only semolina durum wheat sample. This higher value is because the ash content in durum wheat endosperm is inherently higher than other hard wheat grains. On the other hand, while the Argentinean Alimentarius Codex set up an ash limit maximum value to hard wheat, it does not establish any limit for ash in durum wheat semolina.

Determination of Cooking Properties

Table 3 summarizes the results of cooking properties for all samples: optimal cooking time (OCT), cooking loss, water absorption and amylose content in cooking water. The OCT of commercial spaghetti samples varied from 7.5 to 10.5 min. Hard wheat flour spaghetti samples (Com2 to Com5) showed shorter OCT than semolina durum wheat (Com1). Cooking loss, analyzed as weight of total solids lost in the cooking water, varied from 4.4 to 6.4%. This property is commonly used as a predictor of overall spaghetti cooking performance by both consumers and industries (Tudoricá *et al.* 2002).

In spaghetti prepared from semolina, cooking loss values of no more than 7–8% are expected. Water absorption values were within the range of 254–267%, and Com5 and Com1 showed the higher values. Usually, the cooked weight is about three times the dry weight of spaghetti (Dick and Youngs 1988).

Amylose content results were analyzed by regression analysis ($y = 7.51x + 0.092$), regression coefficients ($r^2 = 0.991$) and F statistics (Fexp = 0.828). The amylose contents in cooking water were between 2.0 and 4.7%. Com1 showed the lowest value, whereas Com4 and Com5 showed the higher values at 4.7 and 3.7%, respectively.

The correlation between cooking loss and amylose content in cooking water was observed. This result is in agreement with Fortini's results (1988) that hypothesized that the main constituent of residue from cooking loss was amylose lost from spaghetti during cooking time.

Color of Raw and Cooked Spaghetti

The color of raw spaghetti is an important quality factor for consumers. In pasta products made from semolina, the higher the value, the more desirable the product (Rayas-Duarte *et al*. 1996). Among $L*$, $b*$ and $a*$ parameters, the first two are considered more important as color attributes. A color score has been calculated as $L* + (b* \times 2)/20$, giving a score range from 1 to 10, with 10 being the best qualification (Hareland *et al*. 1995). In Table 4, all color values are shown, including the calculated color score for each sample. Com3 showed the lowest color score (4.1), whereas Com1 and Com5 showed the best color score at 5.9.

The color from raw and cooked spaghetti data was analyzed by PCA. Data were averaged across measurement replications and submitted as correlation matrix (data not shown). The first two resulting dimensions explained 94% of the total variances. The first dimension clearly separated the samples with high $b*$ values, either from raw or cooked spaghetti, and $L*$ values from raw samples. In this way, samples Com2, Com4 and Com5 were associated mainly with the $b*$ variable (raw and cooked) and Com1 and Com3 with the $a*$ (raw and cooked) and $L*$ (only cooked) variables.

Sensory Evaluation

Among all sensory attributes, yellow color, shininess, firmness, chewiness and elasticity can be considered positive attributes; these indicate better pasta quality as higher sample values. In contrast, surface smoothness and surface stickiness can be considered negative attributes that indicating better pasta quality as lower sample values.

TABLE 4.
RAW AND COOKED SPAGHETTI COLOR MEASURED BY MINOLTA 508d
SPECTROPHOTOMETER

Sample	Treatment	$L*$	$b*$	$a*$	Color score‡ (1–10)
Com1	Raw*	49.1 ± 2.0 ab	32.0 ± 1.0 b	3.6 ± 0.2 e	5.7
Com2	Raw*	51.0 ± 1.4 d	33.9 ± 0.8 c	−1.9 ± 0.2 a	5.9
Com3	Raw*	48.2 ± 1.4 a	17.3 ± 0.6 a	0.4 ± 0.1 c	4.1
Com4	Raw*	49.8 ± 1.3 bc	31.6 ± 0.6 b	1.2 ± 0.2 d	5.7
Com5	Raw*	50.7 ± 1.4 cd	33.6 ± 0.8 c	−0.2 ± 0.2 b	5.9
Com1	Cooked†	56.9 ± 1.4 c	12.8 ± 1.1 c	−1.8 ± 0.2 d	4.1
Com2	Cooked†	52.5 ± 1.7 a	15.5 ± 1.5 d	−5.6 ± 0.2 a	4.2
Com3	Cooked†	56.5 ± 2.0 c	3.1 ± 1.3 a	−1.9 ± 0.1 d	3.1
Com4	Cooked†	54.3 ± 1.8 b	10.0 ± 1.6 b	−4.0 ± 0.1 c	3.7
Com5	Cooked†	55.9 ± 1.0 bc	12.5 ± 1.5 c	−4.4 ± 0.1 b	4.0

Values followed by a different letter are significantly different ($P < 0.05$).
Black background reflectance: mean of 10 measurements: $L*$: 25.15 ± 0.07; $a*$: 0.2 ± 0.01; $b*$: –0.3 ± 0.04.
Results were expressed as the mean of replications ± SD.
* Mean of 14 measurements.
† Mean of eight measurements.
‡ Color score: $(L* + (b* \times 2))/20$; score range: 1–10, with 10 being the best qualification (Hareland *et al*. 1995).
$L*$, lightness; $b*$, yellowness-blueness; $a*$, redness-greenness.

Table 5 shows the mean for each attribute resulting from 13 panelists. Except for surface stickiness, all parameters generally showed significant differences among samples. The yellow color of commercial spaghetti samples varied from 4.5 for Com2, followed by Com5 without significant differences among them; the worst score was 1.4 for Com3.

Shininess scores ranged from 4.5 for Com5, then Com2 with a 4.2 score. Com4 obtained the lowest qualification with a score of 2.9. Regarding the firmness attribute, Com5 and Com4 obtained the best qualification, whereas Com1 and Com3 were the worst qualified. Chewiness ranged from 5.1 for Com1 to 3.0 for Com5. As regards to the elasticity attribute, the best qualified sample was Com1, followed by Com2 and Com3, with Com4 being the worst qualified with a score of 2.6. Among the negative attributes, for surface smoothness, Com4, Com2 and Com5 were the best qualified spaghetti samples, whereas Com3 was the sample that the sensory panel qualified as the worst. In the same way, surface stickiness was analyzed; in this case, even though scores ranged from 3.5 to 4.5, no significant differences among all samples were found.

Those attributes considered as positive attributes are represented in Fig. 1. Each one was represented in each axis of the graphic; the higher area implies better pasta quality. Com1 and Com2 were the samples with better

TABLE 5.
SENSORY EVALUATION OF PASTA SAMPLES

Sample	Yellow color	Shininess	Surface smoothness	Firmness	Chewiness	Surface stickiness	Elasticity
Com1	3.8 ± 1.4 bc	3.5 ± 1.5 ab	3.2 ± 1.2 b	4.9 ± 1.5 b	5.1 ± 1.4 c	3.5 ± 2.2 a	5.2 ± 1.4 c
Com2	4.5 ± 1.6 c	4.2 ± 1.3 bc	2.5 ± 1.4 ab	3.3 ± 1.4 a	4.2 ± 1.4 bc	4.4 ± 1.6 a	4.3 ± 0.9 bc
Com3	1.4 ± 0.5 a	3.5 ± 1.1 abc	5.1 ± 1.0 c	4.9 ± 1.0 b	5.0 ± 1.2 c	3.6 ± 1.6 a	4.2 ± 1.6 bc
Com4	3.0 ± 1.0 b	2.9 ± 1.3 a	2.0 ± 0.7 a	2.6 ± 1.1 a	3.5 ± 1.6 ab	3.8 ± 1.5 a	2.6 ± 1.4 a
Com5	4.0 ± 1.2 c	4.5 ± 1.1 c	2.5 ± 1.1 ab	2.5 ± 1.5 a	3.0 ± 1.6 a	4.5 ± 1.7 a	3.7 ± 1.4 ab

Values followed by a different letter are significantly different ($P < 0.05$).
Scale used: discontinuous bipolar of seven points; "1" represented low intensity and "7" represented high intensity in each particular attribute.
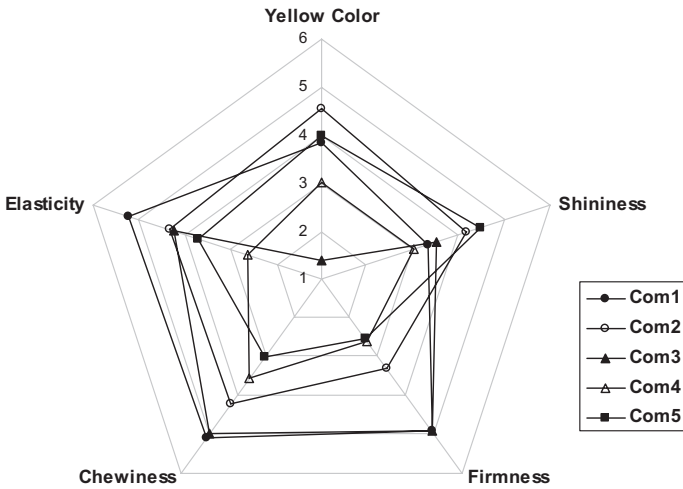Results were expressed as the mean of replications ± SD.

FIG. 1. SENSORY EVALUATION: REPRESENTATION OF POSITIVE ATTRIBUTES

quality, whereas Com4 showed the smallest area which, with the same analogy, could be considered the worst in quality after the sensory evaluation.

The PCA of sensory evaluation suggested that two dimensional representations were sufficient to represent the original data, which were submitted as correlation matrix (data not shown). The resulting first two dimensions explained 86% of the total variances. The first dimension separated the samples into two groups: the first one included Com1 and Com3 with the highest values of firmness, chewiness and surface smoothness, and the second one included Com2, Com4 and Com5 samples with the highest values of stickiness and yellow color.

Cooked Spaghetti Texture Analysis

Firmness of Cooked Spaghetti at Optimal Cooking Time and Overcooking Time. Figure 2 compares the firmness values at different cooking times. Optimal cooking time firmness values were between 13.6 N for Com1 and 6.1 N for Com4. The firmness of the spaghetti samples cooked at 50 and 100% more than their optimal cooking time showed similar profiles, with higher values for Com1 and lower values for Com4 and Com5.

Samples Com1, Com2 and Com3 showed significant differences among different cooking times, whereas Com4 and Com5 did not show differences, which could be interpreted as better resistance to overcooking. Actually, Com4
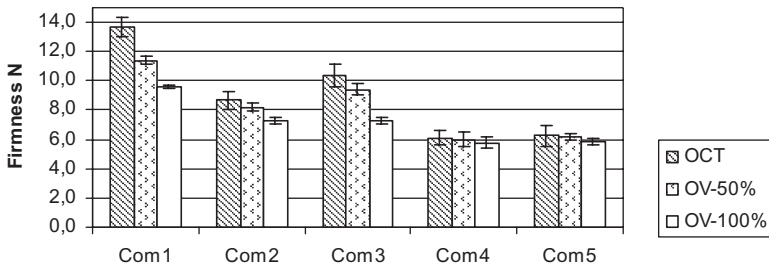
FIG. 2. COOKED SPAGHETTI TEXTURE ANALYSIS: COMPARISON OF FIRMNESS
VALUES AT OPTIMAL COOKING TIME AND EXTENDED COOKING TIMES
OCT, optimal cooking time; OV-50%, overcooking 50%; OV-100%, overcooking 100%.

and Com5 showed lower firmness values even from optimal cooking time, and
they did not worsen after reaching their 50 and 100% overcooking time.

Pasta made from 100% durum wheat semolina maintains a better texture
when overcooked than pasta made from common wheat flour, which was in
coincident with the highest firmness value showed by Com1. The reason that
Com4 and Com5 showed lower firmness values at optimal cooking time was
that pasta produced using common wheat flour is generally inferior in cooking
quality as it is less firm compared to pasta made from durum wheat (Dexter
et al. 1981, 1983; Kim *et al.* 1989).

**Hardness, Adhesiveness, Springiness, Cohesiveness, Chewiness and
Resilience Texture Analysis.** In Table 6 the results for all samples were
shown. Hardness values ranged from 12.96 N for Com3 to 10.87 N for Com2.
Com4 and Com5 presented the higher values in adhesiveness, springiness and
cohesiveness. Chewiness values ranged from 11.38 N for Com3 to 9.50 N for
Com2 and resilience values from 0.060 for Com3 to 0.073 for Com1.

An unexpected no correlation was found between hardness and firmness,
considering the fact that they were measurements with the same objective. The
comparison with the corresponding attribute from the sensory evaluation could
help to recognize the appropriate parameter.

Spaghetti Stickiness Texture Analysis. For stickiness and work of
adhesion, Com4 and Com5 showed (Table 7) the higher values at 2.1 and
2.0 N, respectively, whereas Com1 and Com3 showed the lower values at 0.3
and 0.4 N, respectively. Stickiness and adhesiveness values showed a high
correlation, even though both parameters were determined by different tech-
niques ($r = 0.99$ [$P < 0.01$]). Amylose content was correlated with stickiness
values, $r = 0.93$ (P: 0.02), in agreement with Grant *et al.* (1993).

TABLE 6.
HARDNESS, ADHESIVENESS, SPRINGINESS, COHESIVENESS, CHEWINESS AND RESILIENCE OF SPAGHETTI AS MEASURED BY A TEXTURE ANALYZER (TA-xT2i)

Sample	Hardness (N) (×100)	Adhesiveness (N·s) (×100)	Springiness (×100)	Cohesiveness (×100)	Chewiness (N) (×100)	Resilience (×100)
Com1	1,242 ± 46 c	1 ± 0.2 d	12.3 ± 0.1 c	10.7 ± 0.2 b	1,079 ± 54 c	7.3 ± 0.2 d
Com2	1,087 ± 29 a	4 ± 0.9 b	12.2 ± 0.1 b	10.6 ± 0.3 b	950 ± 27 a	6.8 ± 0.2 c
Com3	1,296 ± 42 d	3 ± 0.8 c	10.5 ± 0.0 a	9.2 ± 0.5 a	1,138 ± 47 d	6.0 ± 0.2 a
Com4	1,197 ± 44 b	11 ± 1.1 a	16.7 ± 0.2 e	13.2 ± 0.5 c	946 ± 58 a	6.4 ± 0.4 b
Com5	1,237 ± 63 bc	11 ± 0.8 a	15.9 ± 0.2 d	12.8 ± 0.4 c	1,001 ± 75 b	6.8 ± 0.5 c

Values followed by a different letter are significantly different ($P < 0.05$).
Results were expressed as the mean of replications ± SD.
All values were calculated for the initial contact area between the sample and probe of 1 cm^2.

TABLE 7.
STICKINESS OF COOKED SPAGHETTIS AS MEASURED BY A TEXTURE
ANALYZER (TA-xT2i)

Sample	Height sample (mm)	Stickiness (N) (×100)	Work of adhesion (N·s) (×100)
Com1	1.76 ± 0.02 d	29 ± 2 a	0.5 ± 0.1 a
Com2	1.59 ± 0.03 c	86 ± 5 b	2.5 ± 0.4 b
Com3	1.72 ± 0.06 d	38 ± 6 a	0.8 ± 0.5 a
Com4	1.45 ± 0.04 a	211 ± 15c	9.9 ± 2.0 c
Com5	1.50 ± 0.05 b	201 ± 22c	9.4 ± 2.0 c

Values followed by a different letter are significantly different ($P < 0.05$).
Results were expressed as the mean of replications ± SD.
All values were calculated for the initial contact area between the sample and probe of 1 cm^2.

The PCA of texture analysis was also represented in two dimensions from the original data submitted as correlation matrix (data not shown). The first two dimensions account for 80% of the total variances. The first dimension separated the samples with high values of firmness, adhesiveness and chewiness, which were linked to Com1 and Com3, whereas stickiness and cohesiveness were related to Com2, Com4 and Com5.

From the PCA analysis, the map derived from the sensory data was similar to that derived from instrumental measurements. The PCA from color measurements, sensory evaluation and texture analysis on the five samples appeared to fall into the same two groups. Com2, Com4 and Com5 formed one group, and Com1 and Com3 formed the other one.

Relations between Instrumental and Sensory Data

A well-understood relationship between the results from the instrumental and sensory procedures is very important as it helps to identify whether an instrumental method can predict the corresponding sensory characteristics (Tang *et al*. 1999).

In this research, excellent correlations between yellow color from the sensory evaluation and its respective instrumental measurement, the b^* value, and between firmness from the sensory evaluation and its respective texture measurement were found. Pearson correlation coefficients were 0.99 ($P < 0.01$) and 0.92 ($P = 0.02$), respectively.

No correlation between stickiness from the sensory evaluation and instrumental measurement was found, which was expected as stickiness from the sensory evaluation did not show significant differences between samples. Besides, no correlations between elasticity and springiness and between chewiness from the sensory and instrumental measurements were found.
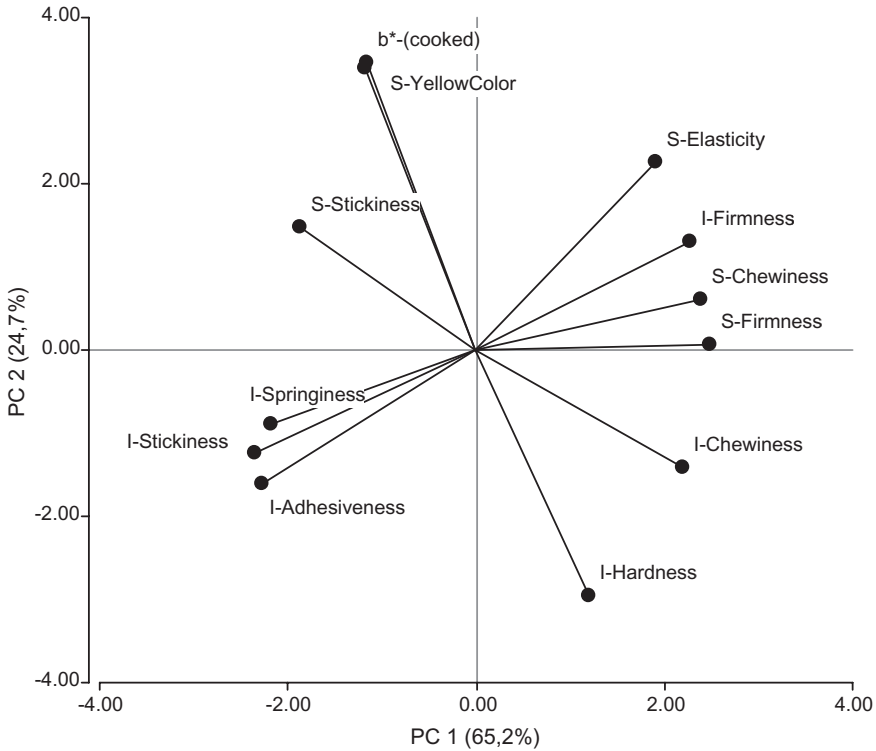
FIG. 3. PRINCIPAL COMPONENT ANALYSIS REPRESENTATION OF RELATIONS
BETWEEN INSTRUMENTAL AND SENSORY DATA FOR COOKED SPAGHETTI
PC, principle component.

In order to analyze the reliability of different instrumental measurements, PCA was carried out (Fig. 3). The data were standardized and submitted to the correlation matrix. The first two dimensions accounted for 92% of the total variance, 65% of which was explained by the first dimension, which separated the samples with higher values of firmness and chewiness, either from the instrumental or sensory evaluation, than samples with higher values of stickiness and yellow color, which were also from the sensory and instrumental measurements.

When the first dimension was calculated, firmness and chewiness, either from the sensory or instrumental measurements, received the higher positive weights, whereas stickiness, from both evaluations, received the higher negative weights. The second dimension remarked the variability introduced by the yellow color and *b** values. From the angles of vector, it is possible to interpret

the high positive correlation between firmness and chewiness, and between the yellow color and *b** values, from the sensory analysis and instrumental measurements, respectively.

As the vector lengths are similar in Fig. 3, they suggest similar contributions of each variable on the PCA representation. It could be observed that, between firmness and hardness, only firmness could be associated with its respective attributes from the sensory evaluation. If this disagreement is taken in conjunction with the divergence between springiness and elasticity, instrumental chewiness and sensorial chewiness, it could undermine the reliable results from Table 6. Probably, the weakening of the association between these instrumental measurements and sensorial parameters was caused by the high degree of sample collapse as was shown by a low value of recuperation between cycles (springiness). This collapse could be related with the wide contact area to reach two cycles of 70% deformation and the short stationary time between compressions.

To conclude, chemical analysis, cooking properties, sensory evaluation and texture measurement were found to be sensitive as quality parameters. A significant relationship between sensory and some instrumental measurements was also found according to Pearson correlation and PCA.

Com1 was the best sample as estimated by sensory evaluation, which was in coincident with the lowest amylose value in water cooking, the highest instrumental firmness and the lowest stickiness showed by this sample.

ACKNOWLEDGMENTS

REFERENCES

AMERICAN ASSOCIATION OF CEREAL CHEMISTRY (AACC). 1995. *Approved Methods of the American Association of Cereal Chemists*, 9th Ed., Methods 44.15 A, 46-30, 08-01, 16-50 and 14-22, American Association of Cereal Chemists, St. Paul, MN.

DEXTER, J.E., MATSUO, R.R., PRESTON, K.R. and KILBORN, R.H. 1981. Comparison of gluten strength, mixing properties, baking quality and

spaghetti quality of some Canadian durum and common wheats. Can. Inst. Food Sci. Technol. J. *14*, 108–111.

DEXTER, J.E., MATSUO, R.R. and MORGAN, B.C. 1983. Spaghetti stickiness: Some factors influencing stickiness and relationship to other cooking quality characteristics. J. Food Sci. *48*, 1545–1551, 1559.

DICK, J.W. and YOUNGS, V.L. 1988. Evaluation of durum wheat, semolina and pasta in the United States. In *Durum Wheat Chemistry and Technology* (G. Fabriani and C. Lintas, eds.) pp. 237–248, American Association of Cereal Chemists, St. Paul, MN.

FEILLET, P. and DEXTER, J.E. 1996. Quality requirements of durum wheat for semolina milling and pasta production. In *Pasta and Noodle Technology* (J.E. Kruger, R.B. Matsuo and J.W. Dick, eds.) pp. 95–131, American Association of Cereal Chemists, St. Paul, MN.

FORTINI, S. 1988. Some specific aspects of durum wheat and pasta cooking quality evaluation in Europe. In *Durum Wheat Chemistry and Technology* (G. Fabriani and C. Lintas, eds.) pp. 231–232, American Association of Cereal Chemists, St. Paul, MN.

FUNAMI, T., KATAOKA, Y., OMOTO, T., GOTO, Y., ASAI, I. and NISHINARI, K. 2005. Effects of non-ionic polysaccharides on the gelatinization and retrogradation behavior of wheat starch. Food Hydrocolloids *19*, 1–13.

GRANT, L.A., DICK, J.W. and SHELTON D.R. 1993. Effects of drying temperature, starch damage, sprouting, and additives on spaghetti quality characteristics. Cereal Chem. *70*, 676–684.

HARELAND, G.A., PUHR, D., WEAR, J.G. and SKUNBERG, M. 1995. Color score: United States Department of Agriculture, Agricultural Research Service in cooperation with the ND state agricultural experiment stations, quality evaluation of durum wheat cultivars. http://wheat. pw.usda.gov/ggpages/gopher/Quality/Durum/1995/95durum.txt.html (accessed May 4, 2006).

KIM, H.I., SEIB, P.A., POSNER, E., DEYOE, C.W. and YANG, H.C. 1989. Improving the colour and cooking quality of spaghetti from Kansas hard winter wheat. Cereal Food World *34*, 216–223.

LEE, S.J., RHA, M., KOH, W., PARK, W., LEE, C., KWON, Y.A. and HWANG, J.K. 2002. Measurement of cooked noodle stickiness using a modified instrumental method. Cereal Chem. *79*, 838–842.

RAYAS-DUARTE, P., MOCK, C.M. and SATTERLEE, L.D. 1996. Quality of spaghetti containing buckwheat, amaranth, and lupin flours. Cereal Chem. *73*, 381–387.

SISSONS, M.J., EGAN, N.E. and GIANIBELLI, M.C. 2005. New insights the role of gluten of durum pasta quality using reconstitution method. Cereal Chem. *82*, 601–608.

STABLE MICRO SYSTEMS. 1995. TA-TX2 Application Study. Comparison of pasta stickiness cooked in hard and soft water. REF: PTA4/PFS. Stable Micro Systems LTD.

TANG, C., HSIEH, F., HEYMANN, H. and HUFF, H.E. 1999. Analyzing and correlating instrumental and sensory data: A multivariate study of physical properties of cooked wheat noodles. J. Food Qual. *22*, 193–211.

TUDORICÁ, C.M., KURI, V. and BRENNAN, C.S. 2002. Nutritional and physicochemical characteristics of dietary fiber enriched pasta. J. Agric. Food Chem. *50*, 347–356.

VIRTUCIO, L. 2003. Oriental noodles, present and future perspectives. Tecnica Molitoria Int. *54*, 146–154.