Cooked Pasta Texture: Comparison of Dynamic Viscoelastic Properties to Instrumental Assessment of Firmness

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ABSTRACT

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Extruded noodles were prepared from durum wheat semolina of variable protein content to provide a series of samples with a range of cooking quality. Firmness of cooked extruded noodles was measured using an Instron Universal Testing Machine and compared with the storage modulus and dynamic viscosity obtained by dynamic rheometry. A strong correlation (r^2 at least 0.87) was found between the Instron values and the rheometer measurements at both optimum and overcooking times, indicating the sensitivity of dynamic rheometry to changes in pasta firmness. The Instron peak force measurement was found to be a more precise indicator of noodle firmness than was peak energy. The rheometer was able to differentiate between samples and to rank the noodle samples in the same order as the Instron did. Although moisture content was shown to have a major influence on the texture of cooked noodles, the differences in moisture between samples were not sufficient to produce the differences measured by either the Instron or by dynamic rheometry.

It is generally accepted that texture is the main criterion for assessing overall quality of cooked pasta. Proper evaluation of pasta cooking quality requires consideration of a number of factors including elasticity, firmness, surface stickiness, cooking tolerance, water absorption, and loss of solids to cooking water (Manser 1981). Taste panels can be used to estimate pasta cooking quality (Menger 1979), but they are time-consuming and impractical when sample size is limited or large numbers of samples are to be evaluated.

In response to these constraints, a number of instrumental methods have been developed that successfully estimate cooked pasta texture parameters (Matsuo and Irvine 1969, 1971; Walsh 1971; Voisey and Larmond 1973; Feillet et al 1977; Voisey et al 1978). Furthermore, a chemical test was developed by D'Egidio and co-workers (1982) that related sensory evaluation of spaghetti glueyness, bulkiness, and firmness to the amount of total organic matter rinsed from the surface of cooked spaghetti.

The use of the Instron Universal Testing Machine (Instron, Canton, MA) is well established for the measurement of pasta firmness (Walsh 1971, Oh et al 1983). It is the instrument recommended by AACC (1983) in approved method 16-50. Like most instrumental tests used to evaluate pasta quality, it involves large deformation measurements on the samples tested.

There has been growing interest in the use of dynamic mechanical tests employing controlled strain and stress to study the fundamental rheological properties of dough (Navickis et al 1982, Abdelrahman and Spies 1986, Dreese et al 1988). These methods are applicable to polymeric materials, such as cooked pasta, displaying viscoelastic behavior. Therefore, it seemed reasonable to use dynamic rheometry to study the viscoelastic properties of cooked pasta and to determine the relationship with Instron firmness values.

MATERIALS AND METHODS

Samples

Samples of No. 1 Canada Western Amber Durum (CWAD) and No. 2 CWAD collected for the 1989 Grain Research Laboratory harvest survey were composited according to protein content to give eight composites with a 11.2–18.5% range in protein content.

Milling

Wheats were cleaned and tempered overnight to 16.5% moisture and milled in single 3-kg lots with a four-stand Allis-Chalmers laboratory mill (Allis-Chalmers, Milwaukee, WI) in conjunction with a laboratory purifier (Black 1966) using the procedure of Dexter et al (1990). The millroom is controlled for temperature (21°C) and rh (60%). Semolina yield range was 61.2–64.5% of clean wheat on a constant moisture basis.

Pasta Processing

Noodles were processed using a Demaco semicommercial laboratory press (De Francisi Machine Co., Brooklyn, NY) under extrusion conditions previously described (Matsuo et al 1978). The extruded rectangular pasta products, referred to as noodles throughout this article, presented a flat, even upper and lower surface to the plate geometry of the dynamic rheometer. When placed side by side, spaghetti or other round pasta products have "valleys" between the strands that can trap water, affecting the rheometry results. Thick and thin noodles were made using dies (Maldari and Sons, Brooklyn, NY) with 1.5 × 20-mm and 0.8 × 20-mm apertures, respectively. Noodles were dried in the 39°C cycle described by Dexter et al (1981).

Noodle Firmness

Cooked noodle firmness was determined as peak force and peak energy with an Instron Universal Testing Machine (model 4201, Instron Corp., Canton, MA) equipped with a 10-kg load cell. Samples were tested in triplicate in completely randomized design. The method used was a modification of AACC (1983) method 16-50. Noodles were cooked to optimum time, defined as when the white core in the center of the noodle disappeared (7 min for the thin and 25 min for the thick noodles), or were overcooked (19 min for the thin and 45 min for the thick noodles). Ten noodle strands, each about 5 cm long, were cooked in 800 ml of boiling tap water for the prescribed time and were immediately drained over a U.S. no. 14 wire sieve. Once drained, the strands were transferred to cold water for 1 min to arrest the cooking process. The samples were drained again over the wire sieve and transferred to a covered container to prevent drying.

Two strands were removed from the container for testing. Excess moisture was removed from the surface by lightly patting the strands between layers of paper towel. They were then placed side by side on an aluminum base plate perpendicular to and centered under a cutting blade similar to that described by Oh et al (1983). The crosshead speed was set at 50 mm/min. The lower limit was 0.5 mm from the base for the thick noodles and 0.1 mm for the thin noodles. For each cooking, four pairs of noodles were sheared in two places, giving a total of eight measurements per replicate.

Cooked Noodle Weight, Cooking Loss, and Moisture Content

Noodle cooked weights and cooking losses were determined

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in duplicate at each cooking time. Ten grams of noodles (12% mb) were cooked for the desired time in 250 ml of boiling tap water. The noodles were drained, cooled in water, drained again, patted dry as described earlier, and weighed immediately. Cooking water was retained and cooking loss determined as described by Dexter and Matsuo (1979). The cooked weight and cooking loss (to account for the lost dry matter) were used to calculate the moisture content of the cooked noodles.

Dynamic Rheometry

The dynamic viscoelastic properties of the cooked noodles were measured in triplicate in a completely randomized design using a Bohlin VOR rheometer (Bohlin Reologi, Edison, NJ) operated with a parallel-plate geometry of 15 mm diameter and a torque element of 93.2 g·cm. Measurements were taken at 25°C in a 0.1- to 10.0-Hz frequency range and below 1.0% strain. Noodles were prepared as described for firmness testing. Once the noodles were patted dry, a 15-mm disk was cut to fit the plate geometry of the rheometer. Three strands were used per cooking, with one disk removed from each strand. The disks were slightly compressed to approximately 1% of sample thickness and allowed to relax for 40 sec before measurements were taken.

The dynamic rheological parameters were storage modulus (G'), loss modulus (G''), loss tangent ($\tan \delta = G''/G'$), and dynamic viscosity (n'). These parameters were obtained using the software analysis program of the rheometer. The rheometer analysis program takes into account the thickness of the sample disk in calculating the various parameters, offsetting differences due to varying degrees of swelling during cooking. A 1-Hz frequency was used for all statistical comparisons.

G' provides a measure of the energy stored and recovered in the sample upon sinusoidal deformation. It is generally taken as an indicator of the elastic character of the sample. Energy dissipated or lost as heat per deformation cycle, or G'', is a measure of the sample viscosity; $\tan \delta$ indicates the relative contribution of the viscous and elastic components; n' normalizes the G'' for the changes in oscillation frequency and is calculated as $G''/2\pi f$, where f is frequency. Faubion et al (1985) provide a good description of the instrumentation and the principles involved in dynamic rheometry of doughs. Application of dynamic rheometry to starch gel network characterization has recently been reviewed by Biliaderis (1992).

Statistics

Statistical analyses were made using the procedures of the SAS software system, release 6.04 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Studies Using Thick Noodles

There is general agreement that protein content is the primary factor influencing pasta quality (Matsuo et al 1982, Autran et al 1986, D'Egidio et al 1990). Therefore, in preliminary experiments, the three durum wheat semolina samples representing the lowest, intermediate, and highest protein content were processed into thick (1.5 mm) noodles to verify that intrinsic differences in cooking quality were present among samples. The cooking quality range was extended further by measuring the texture of each sample at two cooking times.

Analysis of variance of Instron results confirmed highly significant differences ($P < 0.01$) attributable to samples and cooking times (Table I) whether firmness was measured by peak force or by peak energy. Peak force, however, was the more precise of the two measurements as reflected by a coefficient of variation of 5.7% compared with 9.9% for peak energy.

The Bohlin rheometer was used to determine whether the G' and n' of cooked noodles were related to Instron firmness results. The samples were first tested over a range of strains to determine appropriate conditions for rheological testing. Below 1.0% strain, the samples exhibited linear or nearly linear viscoelastic response (Fig. 1). Typical mechanical spectra of optimally cooked noodles are shown in Figure 2. It is apparent that the dynamic moduli show little dependence on frequency, which is characteristic of a true gel network system with stable physical cross-links (Clark and Ross-Murphy 1987).

The rheometer ranked the thick noodles in the same order as the Instron (Table I). Analysis of variance confirmed highly significant ($P < 0.01$) effects on G' due to samples and cooking time. Cooking time had a significant ($P < 0.01$) influence on n'. Significant differences among samples ($P < 0.05$) were found

TABLE I
Quality of Cooked Thick Noodles[a]

Property	Samples Measured 1	4	8
Protein content,[b] %	10.3	13.5	17.6
Optimum cooking time			
Peak force, kg	1.54 c	1.86 b	2.39 a
Peak energy, kg/mm	1.10 c	1.44 b	2.02 a
G',[c] kPa	4.11 c	5.18 b	7.73 a
n',[c] Pa/s	116 b	135 b	203 a
Overcooked			
Peak force, kg	0.97 c	1.13 b	2.02 a
Peak energy, kg/mm	0.83 c	0.97 b	1.32 a
G',[c] kPa	2.66 b	3.28 b	4.49 a
n',[c] Pa/s	84 b	85 b	108 a

[a] Values followed by different letters are significantly different (LSD $\alpha = 0.05$).
[b] N × 5.7, expressed on a 14% mb.
[c] Strain < 1.0%, frequency 1.0 Hz, 25°C.

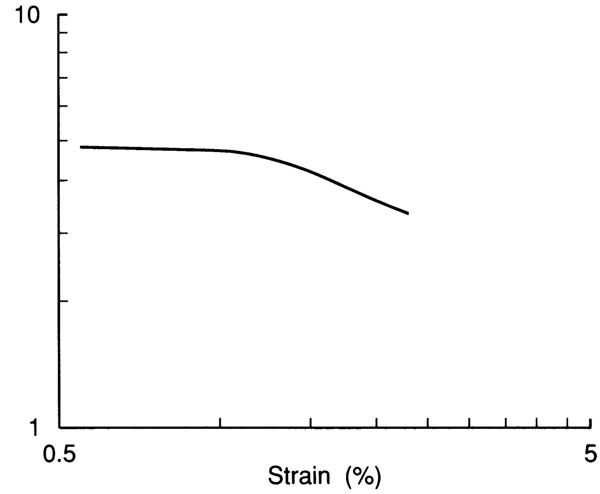

Fig. 1. Typical shear strain sweep of cooked thin noodles. The values of the storage modulus (G') were measured at 1.0 Hz as a function of increasing strain.

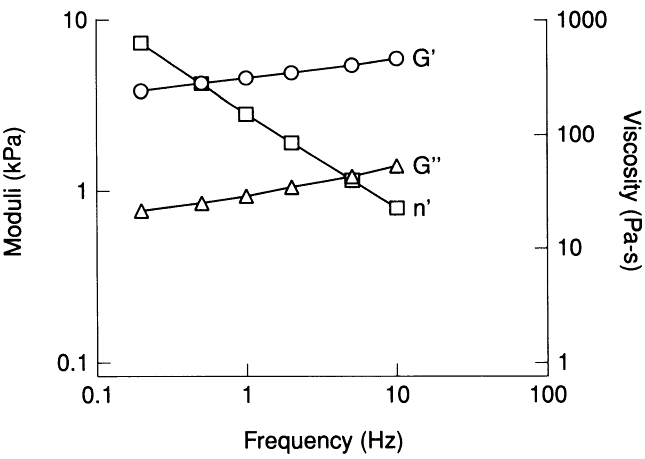

Fig. 2. Typical dynamic viscoelastic mechanical spectra of optimally cooked noodles. G' = storage modulus. G'' = loss modulus. n' = dynamic viscosity.

at optimum cooking time, but, when overcooked, differences in *n'* were not significant.

The trends observed for cooking loss and cooked weight (Table II) are in agreement with previous work on spaghetti (Dexter et al 1983). Cooking loss was significantly ($P < 0.05$) influenced by both cooking time and protein content of samples. Cooked weight was strongly affected by cooking time ($P < 0.01$) but not protein content ($P > 0.05$).

Studies Using Thin Noodles

The results of the preliminary study were encouraging so the study was expanded to include the entire range of samples. It was decided to extrude the samples using a die with a narrower aperture to produce noodles of about 0.8 mm thickness. These thinner noodles more closely match the thickness of popular commercially produced noodles. Rheological tests on thin noodles would be more appropriate for samples of varying cooking quality due to the larger surface-to-volume ratio of the specimen tested. In addition, the thinner noodles cooked in a much shorter time, increasing the number of samples that could be tested per day.

TABLE II
Quality of Thick Noodles

Protein Content[a] (%)	Cooking Loss (%)	Cooked Weight[b] (g)	Moisture Content (%)
Optimum cooking time			
10.3	9.4	26.1	69.4
13.5	8.9	25.6	68.7
17.6	7.1	25.3	67.7
Overcooked			
10.3	15.5	30.7	75.8
13.5	13.7	31.6	76.0
17.6	13.3	31.2	75.5

[a] N × 5.7, expressed on 14% mb.

[b] Based on 10 g of uncooked pasta on a 12% mb.

Both the Instron and the rheometer were sensitive to differences in texture among the thin noodles at optimum and overcooking times. Peak force, peak energy, G′, and *n'* increased at both cooking times as semolina protein content increased. The Instron and rheometer measurements were strongly correlated ($r^2 > 0.87$) at optimum cooking time (Fig. 3) and after overcooking (Fig. 4), verifying that small strain rheological measurements are also sensitive to differences in pasta firmness.

As was the case with the thick noodles, measurement of peak force was more precise (coefficient of variation = 8.4%) than peak energy (coefficient of variation = 12.8%). The AACC (1983) procedure for determining pasta firmness with the Instron recommends the measuring of peak energy as reported originally by Walsh (1971) for spaghetti. For noodles, however, our results indicate that peak force is more sensitive than peak energy and, therefore, a better indicator of differences in firmness between samples.

In general, moisture content has a strong influence on elasticity and viscosity of products being studied by dynamic rheometry (Navickis et al 1982, Biliaderis and Zawistowski 1990, Hansen et al 1991). To determine to what extent the differences in noodle firmness at different cooking times were attributable to differences in moisture content, the samples with the highest and lowest protein content were cooked at two additional cooking times (13 and 25 min). As seen in Figure 5, the moisture content of the two samples was strongly influenced by cooking time. There is no doubt that cooked noodle moisture content is a major factor responsible for the pronounced textural changes attributable to cooking time. However, the relatively small differences in moisture content between samples at a given cooking time (Table III) were

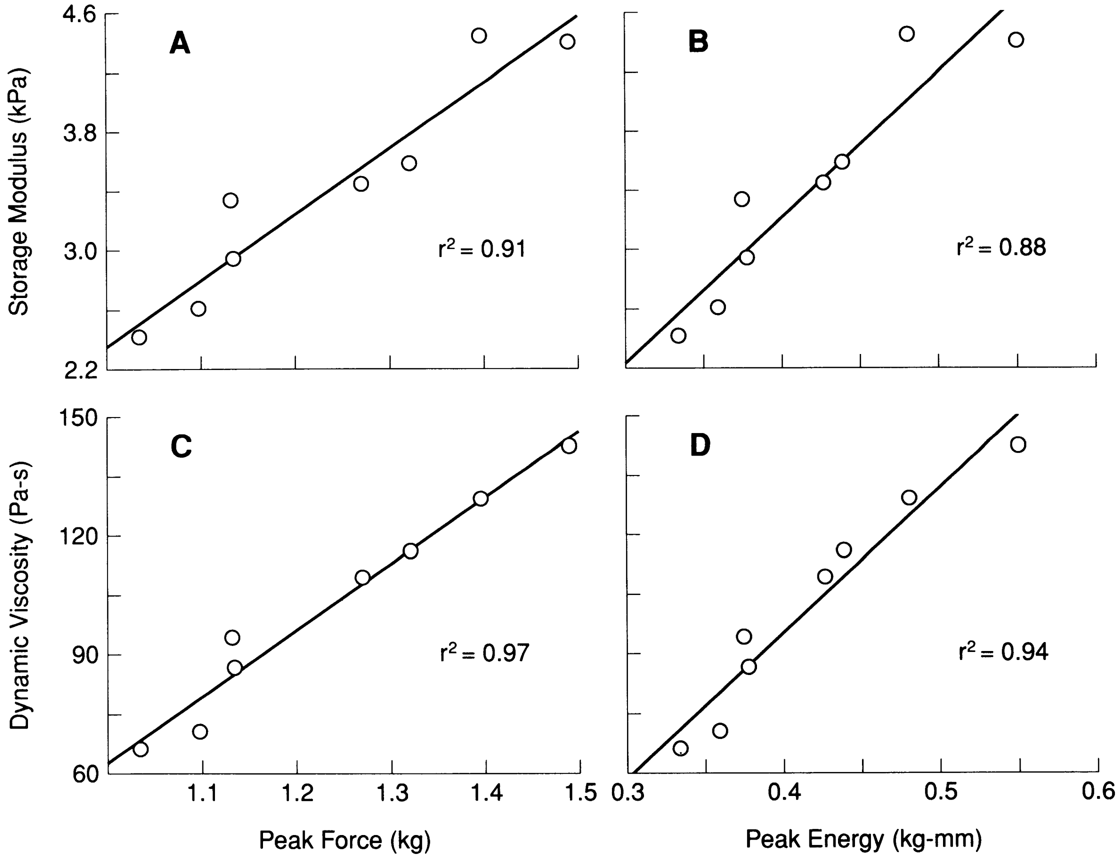

Fig. 3. Relationship between Instron firmness and dynamic viscoelastic responses of optimally cooked thin noodles. **A,** Storage modulus vs. peak force. **B,** Storage modulus vs. peak energy. **C,** Dynamic viscosity vs. peak force. **D,** Dynamic viscosity vs. peak energy.

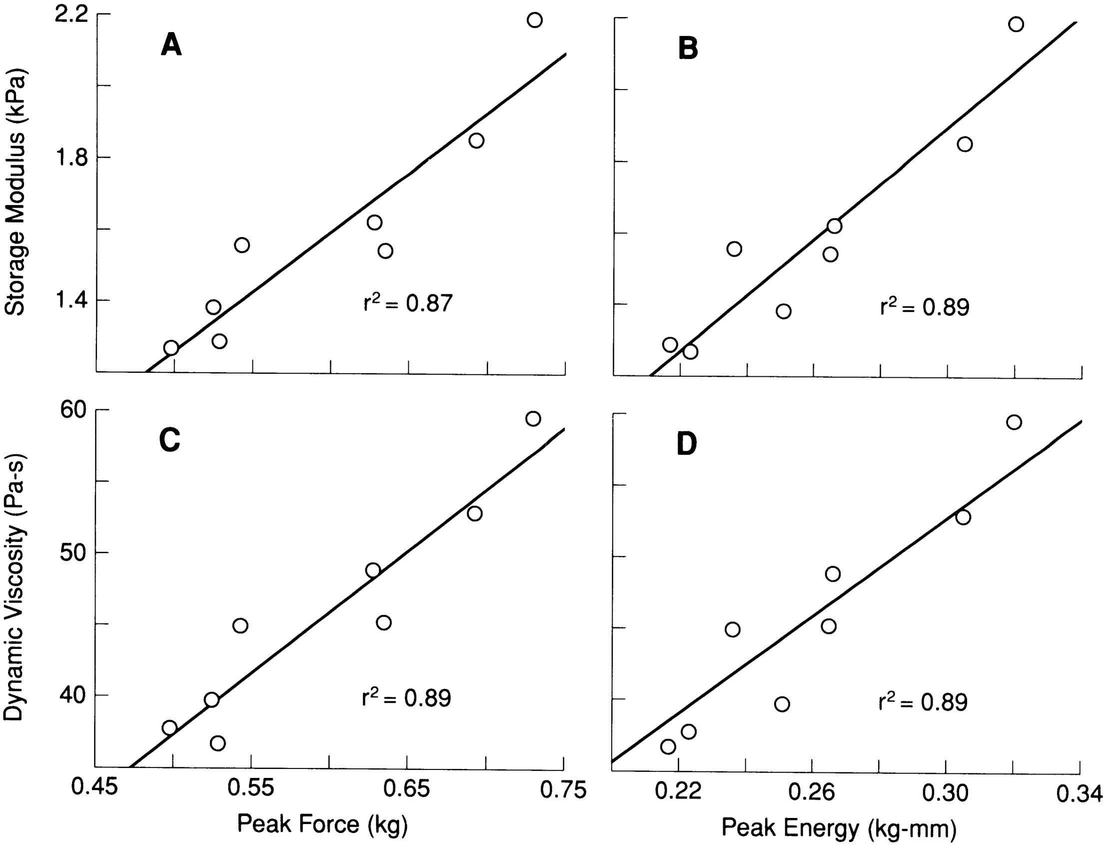

Fig. 4. Relationship between Instron firmness and dynamic viscoelastic responses of overcooked thin noodles. **A**, Storage modulus vs. peak force. **B**, Storage modulus vs. peak energy. **C**, Dynamic viscosity vs. peak force. **D**, Dynamic viscosity vs. peak energy.

TABLE III
Quality of Cooked Thin Noodles

	Optimum Cooking Time			Overcooked		
Protein Content[a] (%)	Cooking Loss[b] (%)	Cooked Weight[b,c] (g)	Moisture Content[b] (%)	Cooking Loss[b] (%)	Cooked Weight[b,c] (g)	Moisture Content[b] (%)
10.3	6.9 a	28.0	70.7	10.1 a	41.3	80.8
12.1	5.9 ab	27.6	70.0	9.6 a–c	43.2	81.6
13.5	6.0 ab	26.7	69.0	8.8 b–d	40.3	80.1
14.6	5.4 b	25.7	67.6	8.5 cd	40.5	80.1
15.5	5.7 ab	26.2	68.3	8.4 d	41.8	80.7
16.6	5.2 b	26.2	68.2	8.8 b–d	39.6	79.7
17.6	5.3 b	26.1	68.1	8.1 d	38.7	79.1

[a] N × 5.7, expressed on a 14% mb.

[b] Means of duplicate results. Means followed by different letters are significantly different (LSD $\alpha = 0.05$). Where means are not followed by a letter, ANOVA showed no significant effects ($P > 0.05$) among samples.

[c] Based on 10 g of uncooked pasta on a 12% mb.

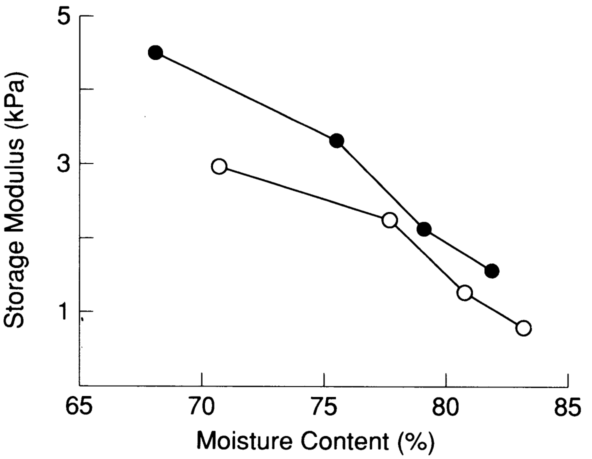

Fig. 5. Storage modulus dependence on moisture content of high-protein (●) and low-protein (○) cooked thin noodles.

found to be not significant ($P > 0.05$). They are insufficient on their own to account for the firmer texture (peak force, peak energy, G′, and n') seen as protein increases. Instead, the observed differences in mechanical properties most likely reflect structural differences in the gluten-starch composite network among samples of cooked pasta.

The cooked weights were not significantly different ($P > 0.05$) among samples for either optimally cooked or overcooked noodles (Table III). The cooking losses, however, were significantly different among samples when overcooked, with cooking loss decreasing as protein increased. This further demonstrates the improved resistance to overcooking of the higher protein samples.

The results of the current study indicate that small deformation measurements by dynamic rheometry are highly correlated with Instron firmness measurements and may prove valuable in further characterizing the fundamental rheological properties of cooked pasta. Such measurements could also be useful in optimization of raw materials and processing conditions for maximum end-product quality.

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