Assessment of Probe Type for Measuring Pasta Texture

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The texture of cooked pasta is an important quality parameter. Reviews on methods of determining the texture of cooked pasta have been written by Voisey and Larmond (24), Cole (6), D'Egidio and Nardi (7), Smewing (22), and Ross (17). Cooked texture is affected by cooking conditions. The effects of cooking conditions on pasta firmness and texture have recently been reported on by Sissons et al. (21).

Traditional Sensory Tests

Historically, texture was measured by trained personnel using mastication. Binnington and Geddes (3) evaluated cooked pasta quality by chewing and touch. They squeezed cooked pasta between their fingers and rated it on cooked firmness/tenderness. These techniques have also been used to evaluate the stickiness of cooked pasta, and they are still used today in the quality control laboratories of some pasta manufacturers. As a source of internal data and to monitor changes in pasta quality over time, these sensory tests are suitable. However, sensory results vary greatly among individuals. For example, Walsh (25) reported that sensory firmness correlated strongly with an instrumental firmness test, but when correlated for each individual in the sensory group, the relationship varied from $r = 0.31$ to 0.88. Similarly, Binnington and Geddes (3) reported that sensory data related to firmness was quite variable, suggesting that detecting small differences might not be reliable and indicating that comparison of results among different groups is limited to detecting large differences. On a commercial level, this raises a question as to the importance of being able to detect texture differences instrumentally that are too small to be detected by sensory perception.

Objective machine tests for firmness are necessary for clear communication across the pasta industry. It is important to have data that do not depend on a single person or small group of people. Sensory evaluation is limited by variability among testers and by the number of samples that can be tested at one time. In research and breeding programs, it is not unusual for 40–50 samples to be cooked in a single day. Using objective instrumental measurements, any trained person should get similar results.

Evolution of Instrument Tests

Early attempts were made to objectively measure the cooked firmness of pasta. Binnington et al. (4) built a "tenderness tester" based on a texture analyzer designed to determine the tenderness of canned fruits and vegetables. They described the instrument as consisting of a plunger terminating in a circular metal disk that rested on the sample, to which a load was applied at a constant rate (12 g/sec) through the addition of mercury until a predetermined reduction in sample thickness was obtained (75%). Initially, the weight of the added mercury was taken as an index of tenderness, but they then incorporated a recording device and developed an equation for tenderness. This method was used by researchers who demonstrated that high protein content resulted in high tenderness scores and that tenderness score was significantly affected by genotype and environment. The Binnington method became an AACCI Approved Method in 1962. In 1969, Matsuo and Irvine (15) reported that the apparatus developed by Binnington et al. (4) was not widely used and indicated that the bite test was still the common test for rating cooked tenderness/firmness.

Matsuo and Irvine (15) designed a machine that used an electric motor and had an output voltage apparatus that applied a continuously increasing force to the cutting edge. A strand of spaghetti was placed in a groove, and a cutting piece that moved downward perpendicular to the strand measured the force required to cut the strand of spaghetti. The time required to cut the strand indicated tenderness—the softer the sample, the shorter the time. However, they found that strands from the same die differed in diameter and that results were affected by small changes in diameter.

Walsh (25) published a procedure for determining the firmness of cooked spaghetti that used a plastic tooth (similar to the TA-47 pasta blade used by Texture Technologies) and a load-sensing cell, strip chart recorder, and automatic integrator (Instron Universal Testing Instrument type TM-M). A single strand of cooked spaghetti was sheared at a 90 degree angle by the "tooth," and each sample was run in triplicate determinations. The test produced a force versus distance recording, where the area under the curve was the amount of work (g·cm) required to shear the cooked spaghetti. Walsh (25) evaluated tooth designs and found a sharp tooth required little force for soft or firm spaghetti, whereas a blunt tooth tended to crush rather than shear the spaghetti. A compromise design had a flat surface and beveled blade. The resulting firmness score was highly correlated with sensory panel scores ($r = 0.81$). This research served as the basis for the current AACCI Approved Method (16-50.01) for determining the cooked firmness of pasta and noodles (1).

The limitations of only measuring the force or work required to cut through spaghetti has been recognized for some time. Kramer and Hawbecker (12) suggested that only measuring force fails to provide a complete description of texture quality. They identified four parameters: 1) deformation, the ability to withstand a certain amount of change in shape before breaking; 2) strength (firmness), a measure of the force required to penetrate or break the sample; 3) uniformity, a measure of the internal characteristics of the bulk of the material; and 4) adhesiveness or stickiness.

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Matsuo and Irvine (16) reported that the problem with recording force of shear is that it is possible for a sample to be firm and yet lack elasticity or springiness. They expressed concern that evaluating firmness/tenderness is inadequate. They replaced the cutting blade with a blunt-edged blade for compression. They presented data that indicated samples with the same tenderness index could differ greatly in compressibility and recovery. Samples that rated poor had a high tenderness index, high compressibility, and low recovery.

Voisey and Larmond (24) discussed the limitations of the Walsh method (25) and other similar methods resulting from measurement of only one point on an individual piece of pasta, pointing out that there is variation within and among spaghetti strands. Voisey (23) and Voisey and Larmond (24) compared several compression-, shear-, and extrusion-type texture probes and found that stress measured by a multiblade shear cell was highly correlated with firmness, and force was highly correlated with firmness and chewiness.

As an alternative to compression tests, other researchers experimented with measuring tensile strength. Shimizu et al. (20) developed an extensiometer that measured the load extension relationship, elastic modulus, energy to breaking point, and stress relaxation. Holliger (11) measured tensile strength and described a machine that measured stretching of cooked spaghetti under continuously increasing force. Tensile strength tests have not been widely embraced in the pasta industry, although they are commonly used in assessing the texture of cooked noodles. Voisey and Larmond (24) reported on research results using the tensile test. Their objective was to determine a quick, effective instrumental technique for testing spaghetti. They reported that tensile stress did not highly correlate with sensory-measured attributes but that tensile force was highly correlated with firmness and chewiness.

Currently, large deformation measurements are most commonly used to evaluate the texture of cooked pasta. There is interest, particularly from a research point of view, in using dynamic mechanical tests employing controlled strain and stress to study the fundamental rheological properties of dough. Edwards et al. (9) found a strong correlation between large deformation measurements using a texture analyzer (Instron) and rheometer measurements at optimum and overcooking times. Small deformation measurements performed using dynamic rheometry could be useful in characterizing the fundamental rheological properties of cooked pasta. Sherman (19) suggested that small deformation measurements could be related to the initial perception of the palate.

Today, AACCI Approved Method 16-50.01, Pasta and Noodle Cooking Quality—Firmness (1), is probably the most common method of determining the texture of cooked pasta, particularly for long goods such as spaghetti and noodles. This method was first approved in 1989 and determines the work (g·cm) required for a plastic tooth (TA-47 pasta blade) machined to a 1 mm, flat cutting edge to cut five strands of spaghetti or an equivalent width of other pasta shapes positioned adjacent to one another. Challenges exist when trying to use this method for short-cut pastas due to the physical constraints of aligning irregular pasta shapes with the straight blade and preventing them from moving during firmness measurements. Because of such challenges, the Kramer shear cell is often used to measure cooked firmness of short goods, particularly those with irregular or unconventional shapes.

Effects of Pasta Formulation on Properties

Historically, pasta was made from semolina, the coarsely ground endosperm of durum wheat. Semolina was hydrated, kneaded into dough, and extruded into the desired shape. During kneading the granular properties of semolina are lost, and a relatively homogenous mass of dough is formed. Today, nontraditional pastas are becoming more accepted and represent a growing market opportunity for pasta manufacturers (14). Nontraditional pastas are commonly made from whole-wheat flour, multigrain flours, and high-fiber ingredients. Many of these ingredients do not change their basic form during pasta processing (13). The occurrence and distribution of these ingredients in pasta affect the physical and chemical composition of the pasta and the resulting cooked texture. Uneven distribution of nontraditional ingredients in pasta, as well as competitive hydration between ingredients, can lead to a nonuniform product. This raises some concerns as to whether a pasta blade probe with a 1 mm cutting edge tests enough of the pasta to adequately determine cooked firmness. There is also interest in determining the effect of nontraditional ingredients on other attributes such as springiness, cohesiveness, and chewiness. Anecdotal evidence exists that suggests some nontraditional pastas can have a firm first bite but rapidly disintegrate in the mouth. If true, using only instrumental measurements of cooked firmness to compare traditional to nontraditional pastas will likely fall short in providing a true assessment of quality with respect to cooked texture.

Research was conducted to determine the suitability of various texture probes for determining cooked pasta texture. Probes evaluated were classified into two groups based on the physical action they perform during a test. Shearing-type probes used included a pasta blade (TA-47), Kramer shear cell (five blades, TA-91), and mini-Kramer shear cell (five blades, TA-91M). Compression-type probes used included an Ottawa cell (TA-245), modified Ottawa cell, and firmness-stickiness rig (HDP/PFS). Texture profile analysis (TPA) measurements were recorded by compression-type probes, whereas only hardness was measured by shearing-type probes. Probes were evaluated for their ease of use and their ability to differentiate formulas (semolina, whole wheat + semolina, whole wheat) and cooking times (optimum cooking time [OCT], OCT + 2 min, OCT – 2 min) for lasagna, macaroni, rotini, and lasagna pasta shapes.

Lasagna, macaroni, rotini, and spaghetti were made at the Durum Wheat Quality and Pasta Processing Laboratory in the Department of Plant Sciences at North Dakota State University, Fargo, and were dried using a high-temperature (70°C) drying cycle (26). Pasta was made from semolina flour (ND State Mill, Grand Forks, ND), whole-wheat flour (ConAgra Mills, Omaha, NE), and a whole wheat + semolina blend (51:49). The cooking procedure followed AACCI Approved Method 16-50.01 (1).

A texture analyzer (TA.XT.plus, Texture Technologies) was used to measure the texture of cooked pasta. The texture analyzer was equipped with a 50 kg load cell. Compression tests were run with all probes using a strain setting of 99%, auto-trigger of 10 g of force, and test speed of 5 mm/sec. TPA settings for compression-type probes used a 1 sec hold time between compressions. Texture attributes hardness (firmness), springiness, cohesiveness, and chewiness were recorded through three measurements for each sample. Texture attributes were defined according to the TPA protocol as described by Bourne (5).

For the pasta blade, 10 spaghetti strands, 2 macaroni pieces, or 2 rotini pieces were oriented perpendicularly to the blade on a flat aluminum platform base. Pasta pieces were placed directly adjacent to one another for the test. Lasagna (5 cm length) was placed on the platform so the direction of extrusion was perpendicular to the blade. For the mini-Kramer shear cell, Ottawa cell, modified Ottawa cell, and firmness-stickiness rig, a set number of pasta pieces was randomly placed in the cell based on the volume of the cell and the load cell capacity. The entire cooked sample was used with the Kramer shear cell.

Sensory analysis was conducted on spaghetti and rotini samples. A trained sensory panel consisting of 10 to 12 panelists evaluated hardness, springiness, cohesiveness, and chewiness of cooked pasta. Two evaluations were performed on different days for each shape, formula, and cooking time combination. Consensus scoring was used within each evaluation.

Ease of Use of Texture Probes

Photographs of the texture probes tested are presented in Figure 1. The pasta blade (Fig. 1A) is the standard probe used in research and by industry for evaluating the cooked firmness of spaghetti and noodles. The probe has a simple design and is easy to use and clean. Made of plastic (Plexiglas or Lexan), it is beveled to a flat 1 mm surface. Often five strands are tested per measurement, allowing multiple measurements to be performed on the same cooked sample. Results are reproducible, and CV is generally ≤5%. The disadvantages of this probe are that small or irregular pasta shapes are difficult to test. Also, the pasta area tested is relatively small, which could be important when testing pasta made from complex formulations in which variations in ingredient uniformity may exist. The pasta blade is not conducive to TPA.

The Kramer shear cell (Fig. 1B) is used by the industry, particularly for evaluating short goods. It is suitable for wide diameter and wide width pasta products. The wide slots that make up the base of the cell allow narrow or small pasta products to fall through before and during a test run. The Kramer shear cell needs to be disassembled, cleaned, and reassembled after each run, increasing the time it takes for multiple evaluations. If cooking a 25 g sample, which is typical for research, there is only one measurement possible per sample. This probe is not suited for TPA due to its shearing action, which destroys the pasta.

The mini-Kramer shear cell (Fig. 1C) must be disassembled, cleaned, and reassembled after each run. Pasta tends to become lodged between the fixed blades, making this probe more difficult to clean than the Kramer shear cell. More care needs to be taken when setting up the probe because the tolerances between the blades and bars of the base piece are small. The narrow slots restrict pasta from falling through before and during a run. The small volume of pasta that can be tested in a single run allows for multiple measurements from a single cooked sample. This probe is not suited for TPA due to its shearing action.

The Ottawa cell (Fig. 1D) has an extrusion/compression action that mimics the pasta firmness-stickiness rig very well. Both the sample base and plunger are made of aluminum. The bottom plate is removable, which simplifies cleaning. The bottom plate is 70 × 70 mm and has 67 holes (6 mm diameter) in alternating offset 5 rows of 7 holes and 4 rows of 8 holes. The hole to sample area ratio is 38.6%. The top plunger needs to be wiped clean between runs. The tolerances between the plunger and the sides of the base cell are quite narrow, making initial setup more challenging than with the pasta blade. The sample base is much deeper than necessary for pasta products because a small sample size will exceed 25 kg of force. Multiple measurements on the same cooked sample are possible.

The modified Ottawa cell (Fig. 1E) is similar to the Ottawa cell in function and mimics the pasta firmness-stickiness rig very well. The sample base is made of aluminum, and the plunger is made of plastic (Plexiglas). The biggest difference from the Ottawa cell is that this cell has a shallow sample base, which for pasta products is adequate. The sample space and plunger are round. The base has a diameter of 78 mm and contains 61 holes (5 mm diameter) in 5 concentric circles. The hole to sample area ratio is 25.1%. Multiple measurements on the same cooked sample are possible, and cleaning between samples is relatively easy compared with the Kramer cells.

A firmness-stickiness rig (Fig. 1F) generally is used for TPA. It is a moderately quick test, but the rig needs to be disassembled, cleaned, and reassembled after each run. It is much easier to clean than the Kramer or mini-Kramer shear cells. The compression action allows for TPA testing. The plunger and cell are made of aluminum. A small sample size allows for multiple measurements from a single cooked sample.

Based on our experience, we rank the pasta blade as the easiest to use; the Ottawa cell, modified Ottawa cell, and firmness-stickiness rig as moderately easy to use; and the Kramer and mini-Kramer shear cells as the most difficult to use.

Discrimination of Pasta Formulations Across Shapes

Table I contains data for hardness of cooked pasta made from semolina, semolina + whole-wheat, or whole-wheat flour as measured by six texture probes and a sensory panel and averaged over cooking time. For lasagna, hardness was greater for semolina than for whole wheat when measured by the pasta blade, Kramer shear cell, and mini-Kramer shear cell. The compression-type probes did not detect significant differences in hardness for the three formulations.

For macaroni, hardness was greater for semolina than for whole wheat when measured by the pasta blade, Ottawa cell, and modified Ottawa cell. Hardness was less for macaroni made from semolina than from whole wheat when measured by the Kramer shear cell. The firmness-stickiness rig was not able to detect any differences in formulation.

For rotini, hardness was greater for semolina than for whole wheat when measured by the pasta blade, Kramer shear cell, mini-Kramer shear cell, and sensory panel. Hardness was less for rotini when made from semolina than from whole-wheat flour when measured by the firmness-stickiness rig. The Ottawa and modified Ottawa cells were unable to detect differences between formulations.

For spaghetti, hardness was greater for semolina than for whole wheat when measured by the pasta blade, Kramer shear cell, mini-Kramer shear cell, and sensory panel. Conversely, hardness was less for spaghetti when made from semolina than from whole wheat when measured by the modified Ottawa cell and firmness-stickiness rig.

Other researchers have reported lower cooked firmness/hardness for pasta containing bran or whole wheat (2,8,13). Declines in firmness have been attributed to

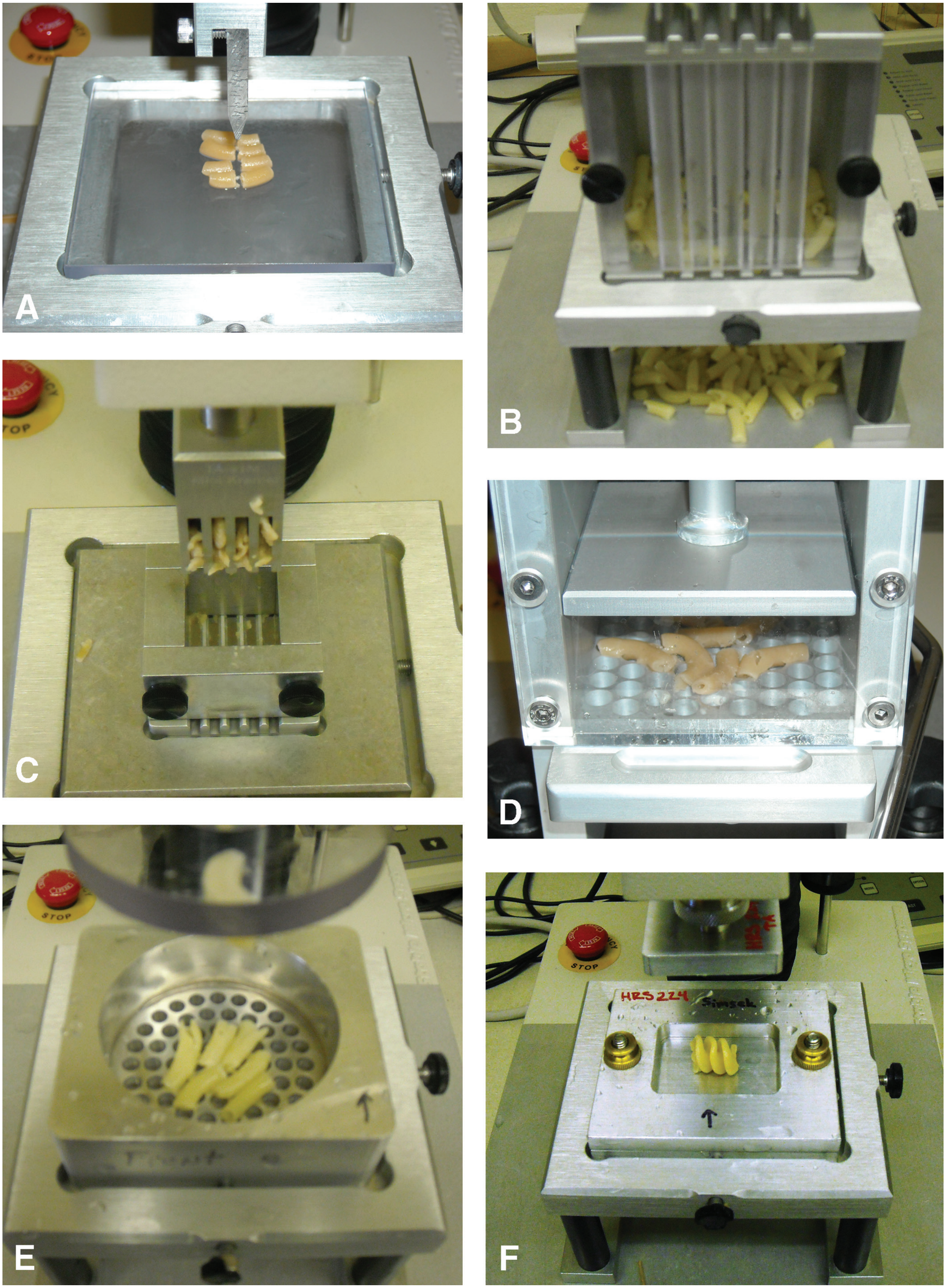

Fig. 1. Photographs of texture probes used: **A,** pasta blade; **B,** Kramer shear cell; **C,** mini-Kramer shear cell; **D,** Ottawa cell; **E,** modified Ottawa cell; and **F,** firmness-stickiness rig.

disruption of the gluten matrix (13) and possibly to the swelling of bran particles during hydration.

In this study, the shearing-type probes tended to provide similar results for hardness as affected by formulation (Table I) regardless of pasta shape. The exception was the Kramer and mini-Kramer shear cells, which gave results that were opposite those of the pasta blade for macaroni hardness.

The compression-type probes detected differences in hardness due to formulation (Table I) less often than the shearing-type probes. Pasta shape did appear to affect the results, however. For example, the modified Ottawa cell was not able to detect differences in hardness for lasagna or rotini but did detect greater hardness for macaroni and less hardness for spaghetti when comparing semolina to whole-wheat formulas (Table I). The firmness-stickiness rig also detected greater hardness for whole wheat than for semolina for spaghetti and rotini. These results for formulation were opposite those for the shearing-type probes and sensory panel evaluations.

The difficulty encountered in detecting differences in hardness when using the compression probes might be related to the high strain (99%) used in the tests. Sasaki et al. (18) compared compressive force for 20, 50, 80, and 95% strain on white salted noodles. They reported that at 20 and 50% strain, noodles made from waxy wheat flour (low amylose) showed lower compressive force than did noodles made from non-waxy wheat flour. However, waxy wheat noodles had higher compressive force than non-waxy noodles when strain was >80%. Sissons et al. (21) reported that compression depth was important. Firmness was greatest at the core of the cooked spaghetti strand at 50% strain. They found no difference in firmness values or variance for samples tested using compression with 75, 90, and 95% strain. We speculate that the bran particles in whole-wheat pasta provided resistance to compression, resistance increased as strain increased, and resistance was detected more easily by the compression probes due to greater probe to pasta contact surface area when using compression-type probes. Reduction of hardness caused by disruption and weakening of the gluten matrix by bran particles could be counteracted by the increased resistance to compression of the bran particles themselves

Table I. Effect of formulation and pasta shape on cooked pasta hardness as measured by six texture probes and a sensory panel (averaged over cooking time)[a]

Pasta Formulation	Plastic Tooth	Kramer Shear Cell	Mini-Kramer Shear Cell	Ottawa Cell	Modified Ottawa Cell	Firmness-Stickiness Rig	Sensory Panel
Lasagna							
Semolina	5,084 a	15,448 a	11,354 a	30,724 a	27,614 a	29,788 a	
Whole wheat + semolina	4,792 b	15,254 a	9,995 b	29,972 a	27,857 a	30,235 a	
Whole wheat	4,277 b	13,878 b	9,362 b	29,762 a	26,742 a	30,128 a	
Macaroni							
Semolina	1,663 a	6,158 c	7,153 b	23,041 a	22,563 a	27,107 a	
Whole wheat + semolina	1,634 a	9,552 a	8,214 a	23,541 a	23,494 a	27,765 a	
Whole wheat	1,317 b	7,935 b	6,739 b	19,834 b	20,172 b	26,882 a	
Rotini							
Semolina	1,956 a	8,228 a	9,388 a	25,123 a	24,788 a	23,021 c	9.2 a
Whole wheat + semolina	1,508 b	8,088 a	9,069 a	25,404 a	24,862 a	25,501 b	9.2 a
Whole wheat	1,283 c	7,028 b	7,942 b	23,929 a	24,460 a	26,994 a	7.8 b
Spaghetti							
Semolina	1,446 a	10,925 a	5,090 a	23,122 a	25,842 b	24,611 c	7.2 a
Whole wheat + semolina	1,084 b	10,317 b	4,852 ab	24,252 a	27,621 a	27,571 b	6.9 b
Whole wheat	844 b	10,035 b	4,589 b	25,201 a	28,945 a	29,558 a	6.9 b

[a] Values in each column for each pasta shape followed by different letters are significantly different ($P < 0.05$).

Table II. Effect of cooking time and pasta shape on cooked pasta hardness as measured by six texture probes and a sensory panel (averaged over formulation)[a]

Pasta Cooking Time	Plastic Tooth	Kramer Shear Cell	Mini-Kramer Shear Cell	Ottawa Cell	Modified Ottawa Cell	Firmness-Stickiness Rig	Sensory Panel
Lasagna							
Undercooked 2 min	6,708 a	18,502 a	13,739 a	36,894 a	33,071 a	37,379 a	
Optimum cooking time	4,094 b	13,629 b	9,458 b	28,878 b	26,228 b	29,325 b	
Overcooked 2 min	3,350 c	12,450 c	7,513 c	24,686 c	22,914 c	23,447 c	
Macaroni							
Undercooked 2 min	2,005 a	12,343 a	11,350 a	26,551 a	26,875 a	33,300 a	
Optimum cooking time	1,468 b	6,278 b	6,362 b	22,443 b	21,849 b	26,417 b	
Overcooked 2 min	1,142 c	5,023 c	4,393 c	17,422 c	17,505 c	22,036 c	
Rotini							
Undercooked 2 min	1,781 a	9,454 a	10,637 a	27,703 a	27,575 a	30,251 a	9.3 a
Optimum cooking time	1,501 b	7,336 b	8,455 b	24,451 b	23,734 b	24,210 b	8.7 ab
Overcooked 2 min	1,465 b	6,554 c	7,307 c	22,301 b	22,801 b	21,055 b	8.1 b
Spaghetti							
Undercooked 2 min	1,234 a	11,819 a	5,194 a	25,814 a	29,714 a	30,307 a	7.3 a
Optimum cooking time	1,157 a	10,578 b	4,920 a	23,823 a	26,951 b	26,222 b	7.0 b
Overcooked 2 min	983 b	8,879 c	4,417 b	22,938 a	25,743 b	25,211 b	6.6 c

[a] Values in each column for each pasta shape followed by different letters are significantly different ($P < 0.05$).

when measured with compression-type probes at high strain. This may help explain why formula differentiation with compression-type probes was less successful than with shearing-type probes.

Discrimination of Cooking Time Across Pasta Shapes

Hardness. Table II contains means for pasta hardness as affected by cooking time when measured by six texture probes and a sensory panel and averaged over formulation. Cooked pasta hardness was greater for undercooked than for overcooked pasta as measured by all probes and the sensory panel. Lasagna and macaroni hardness was greatest for undercooked, intermediate for optimum cooked, and least for overcooked pasta as measured by all probes. For rotini, optimum cooked and overcooked pasta had similar hardness when measured by the pasta blade, Ottawa cell, modified Ottawa cell, firmness-stickiness rig, and the sensory panel. The Kramer and mini-Kramer shear cells differentiated hardness for all three cooking times for rotini. The ability to differentiate all three cooking times was more variable for spaghetti. Spaghetti hardness for undercooked and optimum cooked pasta was similar when measured by the pasta blade and mini-Kramer shear cell. Spaghetti hardness for optimum cooked and overcooked pasta was similar when measured by the modified Ottawa cell and firmness-stickiness rig. The Ottawa cell was unable to detect differences between cooking times for spaghetti.

Undercooked pasta has a center core with low moisture content and ungelatinized starch; as cooking continues the moisture content increases, and the ungelatinized starch disappears. It has been well documented that cooked pasta firmness or hardness decreases with increased cooking (13,21). Gonzalez et al. (10) reported that water migration to the center of lasagna corresponded to a decline in cooked hardness. They concluded that moisture migration to the center of the pasta increased the plasticization of the biopolymers, which resulted in a lower peak force.

Table III. Effect of cooking time, formulation, and pasta shape on cooked pasta springiness as measured by three texture probes and a sensory panel[a]

Pasta Formulation/Cooking Time	Ottawa Cell	Modified Ottawa Cell	Firmness-Stickiness Rig	Sensory Panel
Lasagna				
Semolina	0.596 a	0.658 a	0.742 a	
Whole wheat + semolina	0.578 a	0.553 b	0.666 a	
Whole wheat	0.492 a	0.528 b	0.758 a	
Macaroni				
Semolina	0.592 a	0.642 a	0.639 a	
Whole wheat + semolina	0.547 a	0.433 b	0.518 b	
Whole wheat	0.348 b	0.362 c	0.478 c	
Rotini				
Semolina	0.361 a	0.387 a	0.327 a	1.9 a
Whole wheat + semolina	0.349 a	0.331 b	0.294 ab	1.7 b
Whole wheat	0.250 b	0.238 c	0.270 b	2.0 a
Spaghetti				
Semolina	0.600 a	0.583 a	0.580 a	6.8 a
Whole wheat + semolina	0.576 a	0.570 a	0.470 b	5.9 b
Whole wheat	0.491 b	0.514 b	0.428 b	5.8 b
Lasagna				
Undercooked 2 min	0.331 c	0.357 c	0.500 b	
Optimum cooking time	0.555 b	0.571 b	0.722 a	
Overcooked 2 min	0.742 a	0.686 a	0.790 a	
Macaroni				
Undercooked 2 min	0.399 b	0.386 b	0.348 b	
Optimum cooking time	0.495 a	0.479 a	0.542 a	
Overcooked 2 min	0.491 a	0.478 a	0.566 a	
Rotini				
Undercooked 2 min	0.272 c	0.269 c	0.244 b	1.4 c
Optimum cooking time	0.320 b	0.318 b	0.297 a	1.8 b
Overcooked 2 min	0.351 a	0.345 a	0.318 a	2.2 a
Spaghetti				
Undercooked 2 min	0.613 a	0.595 a	0.521 a	6.2 a
Optimum cooking time	0.555 b	0.556 b	0.494 a	6.2 a
Overcooked 2 min	0.540 b	0.546 b	0.517 a	6.2 a

[a] Values in each column for each pasta shape followed by different letters are significantly different ($P < 0.05$).

In general, all probes, with the exception of the Ottawa cell for spaghetti, differentiated undercooked from overcooked pasta. It did not appear that shearing-type probes performed better than compression-type probes when differentiating all three cooking times (Table II). All three cooking times were differentiated for lasagna and macaroni shapes by all six probes.

Springiness. Springiness was measured using compression probes. Differences in springiness as affected by formulation were not detected for lasagna by the Ottawa cell or firmness-stickiness rig but were greater for semolina than for whole wheat when using the modified Ottawa cell (Table III). For macaroni, rotini, and spaghetti, springiness was greater for semolina than for whole wheat regardless of the probe used. Sensory analysis indicates that springiness was greater for semolina than for whole wheat for spaghetti.

Springiness was greater when pasta as overcooked than undercooked for lasagna, macaroni, and rotini regardless of the probe used (Table III). These results agree with sensory data for rotini—springiness was greatest for semolina, intermediate for the whole wheat + semolina blend, and least for whole wheat. Interestingly, springiness was greater when pasta was undercooked than overcooked for spaghetti when tested using the Ottawa and modified Ottawa cells. The effect of cooking time on springiness of spaghetti was not detected by the firmness-stickiness rig or sensory panel. It is possible that more differences in springiness could have been detected if a lower strain was used for testing. At 99% strain, the probe deformed the samples to a great extent and perhaps minimized elastic recovery after deformation.

Springiness results across formulations and cooking times do not provide the same results as those for hardness values. This is evidence that hardness values do not by themselves accurately represent all existing differences in cooked pasta texture.

Conclusions

These data indicate that results for pasta texture are dependent on pasta shape, formulation, cooking time, and type of texture probe used. Therefore, factors such as ease of use, importance of measurement of multiple texture attributes, pasta formulation, and level of discrimination desired must be assessed by the user when selecting a probe type for monitoring pasta texture.

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