Rice Stickiness. I. Determination of Rice Stickiness with an Instron Tester[1]

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ABSTRACT

An objective method of measuring the surface stickiness of cooked rice with an Instron tester is described, and the physical interpretation of the values obtained is discussed. The coefficient of variation ($s/\bar{x}$) for the Instron itself was less than 5%. Factors in cooking and handling the rice that add 15% more to the coefficient for the method are identified and discussed. Reproducibility was adequate enough to allow easy distinction between sticky and nonsticky varieties and was substantially improved by optimizing the water to rice ratio used during cooking. Potential methods of using a Gelometer and a Farinograph to measure the stickiness of a paste of cooked rice are briefly discussed.

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In the United States, commercial rice varieties are divided into three market classes—long, medium, and short grain. These three groups differ in many characteristics besides grain length. Long grain rices tend to be bland, flaky, and dry when cooked, whereas the short and medium rices tend to be sticky, moist, and flavorful. Medium and short grain classes are generally referred to as the "sticky rices," and correspond to the japonica varieties. The long grains correspond generally to the indicas.

Stickiness is greatest when a rice is freshly harvested and decreases with aging or when treated to accelerate aging. Consumers who prefer less stickiness favor aged rice, whereas those who prefer maximum stickiness consider aged rice to be deteriorated. Other subtle changes in flavor and texture accompany the reduction of stickiness.

Most Americans prefer that their table rice be long grain. Because the yield per acre and the milling yield of long grain rice is usually less than that of sticky varieties, long grain rice often carries a premium price. In California, where high yields of sticky rice are obtained, consumers desiring long grain must pay transportation costs as well (eg, California sticky rice yields in 1979 were 150% of Texas long grain yields) (Walsh and Johnson 1981). For many years, plant breeders in California have sought to develop cold-tolerant, high-yielding long grain varieties with traditional long grain eating characteristics.

In 1975, we began a study of treatments that accelerate the aging of sticky rice. We later described a method of measuring stickiness and treatments that reduced stickiness (Mossman and Fellers 1976). In applying the Instron method to a wider range of samples, however, we found some problems in reproducibility. In this article, we describe the Instron stickiness method and the determination of the amount and source of variation. A brief description of potential methods that employ a Gelometer or Farinograph is also given. A separate publication covers correlation of Instron stickiness with organoleptic stickiness, variation in Instron values of 12 untreated rices, and some methods of stickiness reduction (Fellers et al 1983).

Cooking Methods

The literature contains descriptions of many tests that distinguish between indica and japonica varieties or that measure changes in the properties of a variety after storage or treatment (International Rice Research Institute 1979, Simpson et al 1965, Webb and Stermer 1972). In addition to the testing procedures themselves, the methods for preparing the rice for testing also vary widely. The following variations have all been used in instrument or panel evaluation of cooking procedures: large or small sample size, excess or limited water, optimum or fixed rice to water ratios, direct or indirect boiling, steaming, or oven heating, fixed or optimum cooking times, and various cooling procedures. For panel evaluation, Batcher et al (1963b) compared a standard oven cooking method to a wide variety of native cooking methods and rices from 21 countries and concluded: "Whether the rice was prepared in the oven, steamed, cooked in small, medium, or large amounts of water, or in water with oil added, the palatability characteristics of the cooked product from a given sample and country were similar." This implies that varietal differences will be evident regardless of the cooking method used as standard. During studies of cooking kinetics, Suzuki et al (1976) found that presoaking reduced the cooking time required to soften the center of the rice kernel (optimum). Their graphs indicate that a cooking time of about 25 min at 100° C is needed to reach optimum without presoaking. Cooking to optimum has been recommended by some (IRRI 1979). Others have reported that testing for doneness by

[1] Mention of a trademark or proprietary product does not constitute recommendation of the product by the USDA over others that also may be suitable.

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pressing rice kernels between glass plates did not correlate well with panel estimation of doneness (Hogan and Roseman 1961). Kurasawa et al (1962), who used both excess and limited water for cooking, pointed out that solids leached during cooking are removed in excess water but are redeposited when limited water is used.

Evaluation Methods

Rice evaluation methods have been reviewed (IRRI 1979). Many workers have used organoleptic methods, often combined with chemical or instrumental methods, to evaluate cooked rice. Schutz and Damrell (1974), who used a trained panel to rate 15 sensory characteristics of 20 varieties, found stickiness to be second only to tenderness in importance to the consumer panel.

Many instruments have been used to evaluate texture (deMan 1976, Szczesniak 1963), and a few have been particularly useful in evaluating whole cooked rice. Ferrel et al (1960) used a specially constructed screening device to follow changes in rice stickiness after treatment. The percentage by weight of single kernels passing through the screen (a smooth metal plate perforated with holes 3/16 in. in diameter) after shaking 2 min (reciprocating 1 in. at 335 cycles per min) was used as a measure of stickiness reduction and was referred to as the separation index. Kurasawa et al (1962) employed a beam balance to measure adhesion of rice varieties, along with organoleptic and chemical assessment (iodine value). In his method, rice was pressed between plates attached below one pan of the balance, by a 500-g weight in the pan. The weight was then removed, and weight was gradually added to the opposite pan until the plates pulled free. The weight required to separate the stuck plates was the measure of stickiness. Other workers have correlated organoleptic and chemical results with results from a parallel plate plastometer (Dienes and Klemm 1946), and more recently a General Foods Texturometer (Friedman et al 1963). The plastometer and the viscoelastometer measure sample deformation between horizontal plates under load and the recovery when the weight is removed. Stickiness, as such, is not measured. The Texturometer is comprised of an articulated jaw that chews the food while the force resisting the chewing is recorded against time. The graph produced by several successive chews is called the texture profile of the food. The negative part of the graph relates directly to stickiness. The Instron Universal Tensile and Compression Tester has been used increasingly to obtain similar profiles or single texture measurements (Breene 1975), and less expensive instruments have become available along with special attachments for compression, extrusion, or tensile tests. Voisey (in deMan 1976) examined errors that may occur when Instron type instruments are used for texture tests if certain precautions are not taken in the design of the test. To reduce or avoid errors, he recommended use of a high-speed recorder (or direct digital device), slow speeds, and soft materials. Measurements should be taken only after the crosshead reaches full speed (eg, reciprocal motion causes errors due to backlash and inertia of crosshead and recorder). The use of single-measurement tests to measure complex properties was investigated by Bourne (1968). He concluded that, although texture is always complex, when all the various textural characteristics of a food change together in the same direction and at the same rate, the texture measurement of that food appears to be simple, and any characteristic can be used as a measure of all of the others. Thus, single-measurement tests are appropriate for properties that change in parallel. The Brabender Plastograph, which is a Farinograph with a smaller bowl, has been used in Japan for measuring the rheological characteristics of cooked rice (IRRI 1979).

Stickiness Theory and Units of Measurement

The literature contains discussions of the forces involved in stickiness and the units appropriate for a stickiness test. Dienes and Klemm (1946) used Stefan's equation to show the relationship between force and viscosity with the parallel plate plastometer. Stefan's equation, rearranged according to Bikerman (1947) is:

$$Ft = \tfrac{3}{4}\,\eta\, r^2\,(1/h_1^2 - 1/h_2^2)$$

where F is force in dynes (1 g force = 980 dynes), t is time of test in sec, η is viscosity, r is sample radius, and h_1 and h_2 are sample height before and after the test. At a given viscosity, the force is huge for quick separations, usually causing failure by exceeding the tensile strengths of the material. Bikerman (1947) compared tackiness and adhesion of solids and liquids, and explained that liquids flow according to Stefan's equation, but that solids rupture at weakened spots, with impurities and air contributing to adhesive failure. Banks and Mill (1953) reported that cavitation occurs in liquids when the plates are pulled apart too fast, causing a deviation from Stefan's law. They felt that although viscosity (rather than adhesion) was the source of the force resisting separation, other factors contribute and may reduce the effective stickiness. Thus Stefan's law is valid but not sufficient. Adhesion theory in terms of surface free energy and forces was reviewed by Good (1977). Dwight (1977) presented studies on the fracture of adhesive solids with some discussion of adhesive and cohesive forces. Most authors agree that the negative curve obtained during the instrumental measurement of stickiness is proportional to the work needed to overcome the stickiness (deMan 1976). Some authors use force-time units (impulse), rather than force-distance units (work). The contributions of the deformation-relaxation component and of the speed of the test to the curve obtained have been mentioned by Voisey (deMan 1976), but little else has been discussed about the curves themselves. Although most say that because part of the sample remains on the plates after rupture, the source of the stickiness forces is actually cohesion (of sample to itself) rather than adhesion (of sample to plate). They often use terms such as "adhesion" or "adhesiveness," however, to describe negative curves. Thus, a single set of units is not commonly used, nor is a full treatment of the interpretation of the negative curve available.

MATERIALS AND METHODS

Three instruments were evaluated for their ability to measure stickiness: the Brabender Farinograph (C. W. Brabender Instruments Inc., South Hackensack, NJ); the Bloom Gelometer (Precision Scientific Co., Chicago, IL); and the Instron Tensile Tester, model TM (Instron Engineering Corp., Quincy, MA). The Gelometer and Farinograph measure the properties of a paste of cooked rice, whereas the Instron measures adhesion of the intact grains without deforming them very much. Because the Instron focused on the surface properties we wished to measure, it was chosen for our standard stickiness method.

The Standard WRRC Instron Rice Stickiness Method

Eight grams of untreated rice (as-is moisture basis) was placed in a 30-ml beaker to which a weighed amount of distilled water was added. The beaker was then covered with a watch glass and placed on a screen above boiling water in a covered pan 25 cm in diameter and 15 cm deep (Fig. 1). After steaming 20 min, the heat was shut

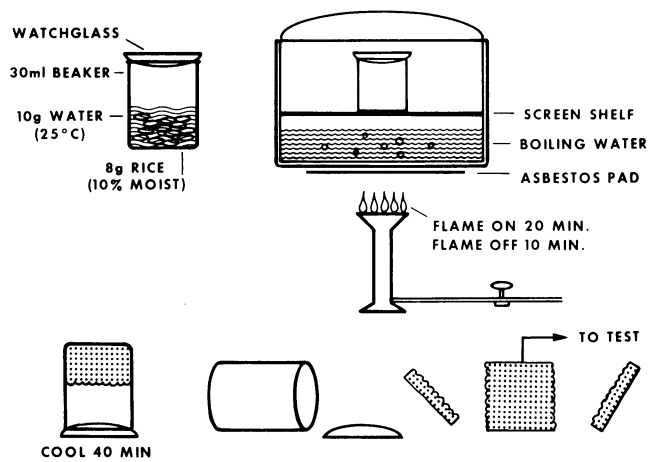

Fig. 1. Cooking procedure for the Instron test.

off and the sample was held in the pan an additional 10 min. It was then removed and placed upside down on its cover glass (to prevent condensate drip) to cool for 40 min at room temperature before testing. Two grams of rice was taken from the center of the rice without mixing for testing on the Instron.

The Instron tester consists of two horizontal, parallel, stainless steel plates, the top one movable up or down at a constant rate, the bottom one stationary with a sensing device attached to it to measure the force pressing (positive) or pulling (negative) against it. Before the test, the instrument was set at zero at the center of the recorder chart, and the full-scale deflection was calibrated with a known weight (in grams). For testing, the empty platform was balanced to zero, and a 2-g sample of cooked rice was piled on it as high as possible without packing. The crosshead was lowered at 0.5 cm/min while the recorder chart moved at 25 cm/min. As pressure on the rice increased, the pen moved in the positive direction (Fig. 2). At 640 g of pressure the crosshead movement was stopped for exactly 10 sec, during which time the sensitivity switch was increased to maximum, causing the pen to move off-scale. After the 10 sec, the crosshead was moved upward at the same speed, causing the pen to cross zero (negative) and return. When it recrossed negative 2, the test was stopped. A line was dropped from this crossing point to zero, the long tail on the curve was thus cut off, and the total negative area was taken as representing the stickiness value. An integrating attachment was used to obtain a digital readout proportional to the area. The stickiness values are the integrator units converted to g·cm units (grams adhesive force and centimeter crosshead movement) by multiplying by the appropriate factor.

Details of the WRRC Instron Method

The rices (one lot of Bluebelle, a Texas long grain, and several lots of Calrose, a very sticky California medium grain) were obtained as paddy, stored in plastic bags inside metals cans sealed with friction lids at 2° C, and milled as needed. A McGill sheller, a McGill no. 3 mill using a 12-lb weight for 1 min, and a Hart separator were used to obtain the head rice (H. T. McGill Inc., Houston, TX; and Carter-Day Co., Minneapolis, MN). One kilogram of rough Calrose rice yielded 168 g hull, 80 g bran and polish, and 640 g head rice; 1 kg of rough Bluebelle rice yielded 192 g hull, 92 g bran and polish, and 652 g head rice. We assumed that changes in stickiness (aging) would be retarded by the cold and would be much slower in paddy than in milled rice. Calrose, our stickiest variety, however, decreased significantly in stickiness over the year at these conditions, and samples drawn, milled, and held four months before testing were not significantly different from those stored as paddy during the same four months and milled just before testing. Deep freezing to prevent changes had been avoided because of the possibility that such treatment might irreversibly alter the sample.

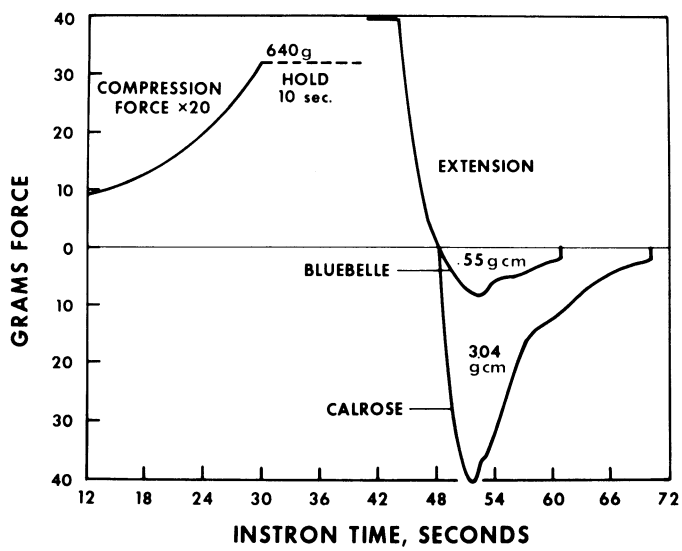

Fig. 2. Stickiness of a long and a medium grain rice by the Instron. The Instron moves at 0.0083 cm/sec.

For most of our work, we used a ratio of 1.25 water to rice (10 g water per 8 g rice) because that amount of water was completely absorbed by the rice during cooking (Fellers and Deissinger 1983, Fellers et al 1983, Lorenz et al 1978). However, 1.50 water to rice (12 g water per 8 g rice) gave much better precision. The temperature of the 10 g of water in the covered beaker in the covered steaming pan was measured and found to rise above 95° C within 5 min of the start of steaming.

Preliminary statistical analysis showed that variation among steaming pans was minor, but variation among beakers became significant at about the 5% probability level. Our design used four beakers with two 2-g samples drawn from each beaker for a total of eight Instron runs per rice sample. The beakers were all steamed in the same pan, or in four separate pans, depending on the size of the particular experiment. A practical limit of six beakers fit in one of our pans, allowing the beakers to be placed equidistant from the center of the pan. The content of the pan was run as a set, with the order of presentation to the Instron randomized.

Consistent placement of the 2-g rice sample on the platform was found to be an important but difficult step. We standardized on placing in a pile as high as possible without packing.

Calibration Check

The Instron compression cell was not intended for negative measurements (extension or adhesion). To test the validity of the positive calibration in both positive and negative modes, a Mettler top-loading balance (model K-7T, Mettler Instrument Corp., Princeton, NJ) was placed on the movable crosshead and a wire run from the bottom of the weighing pan to the cell platform. The response of the Instron recorder was compared to the dial of the balance under various load conditions in both positive and negative modes, always with the same result. The positive and negative modes were each linear and had no measurable deviation, and the deviation between the slopes of the positive and negative lines was extremely small (1% maximum), well within our contemplated use of the instrument.

Because the crosshead and recorder charts move at known constant rates during the test, the chart can be calibrated in that direction either in seconds (duration of test), distance of crosshead movement, or distance of chart movement. We calibrated the chart in centimeters of distance of crosshead movement for that dimension and grams of force in the other (based on the weight used in calibrating the platform). The areas were reported in the corresponding g·cm units. The choice of g·cm (work) units over g·sec (impulse) units and the interpretation of the values obtained will be discussed later.

Moistures were determined by the AACC air-oven method for paddy, and by the vacuum-oven method for milled rice (AACC 1976). Snedecor and Cochran (1967) described the statistical tests given in the text.

Developmental Aspects of the Instron Method

The first developmental work was done using the standard method as a whole as described above but with one or more conditions varied. Then experiments were done with isolated parts of the method.

Three different operators ran the test repeatedly on Calrose and Bluebelle rices to determine whether variation among operators was significantly greater than variation among samples by one operator. Next, placement of the sample on the platform was examined (within-operator variability). Then, on Calrose rice, the water to rice ratios and the time between cooking and running the samples were investigated. Using 8 g of rice, the water added was varied from 6 through 16 g in 2-g increments (a ratio of .75 to 2.0 water to rice), and the samples were cooked and run as before in an order designed to allow proper statistical analysis. The time at which each sample was run was varied so that the total cooling time varied from 1 to 2.25 hr. The intentional variables of water and time accounted for only 50% of the variation in stickiness. The rest was

said to be caused by random error or by an uncontrolled major influence. This result prompted us to shift our attention to isolating, measuring, and explaining the cause of variation. Possible sources were variation in the rice itself, the cooking, the sampling for the Instron, the presentation or running of the tests, or variability within the Instron itself. Each of these was examined separately, beginning with the Instron and working backwards. To test the variability due to the Instron alone, pure compounds, a rice slurry, and rice of various sample sizes were compared. Variation due to handling was determined by comparing replications with and without removal from the Instron. Finally, variability due to cooking procedure was estimated by determining the effect of cooking on the moisture distribution in the cooked rice within the beaker.

Farinograph and Gelometer Methods

In the Farinograph, two specially shaped horizontal paddles work a paste or dough in an enclosed trough while its resistance against the paddles is recorded against time. The Gelometer measures the weight in grams required to force a plunger of 1.2-cm diameter into a gel, dough, or paste to a depth of 4 mm from the surface.

To obtain rices of one variety having different levels of stickiness, the milled rice was exposed to a blast of fluidizing, heated air in a pilot toaster (Surface Combustion Co., Toledo, OH). Heat-treated samples were weighed on the same moisture basis as the corresponding controls, thus compensating for moisture lost during the heat treatment.

For these tests, 36 g of untreated, milled rice at about 10% moisture (or the treated equivalent) were placed in a 150-ml beaker, soaked in water 2 hr, drained, and water added to make a total of 81 g (1.25 water to rice ratio). The beaker was covered with a watch glass and the sample steamed as described for the Instron method. After cooking, the entire sample was placed in the small bowl of the Farinograph and kneaded for 20 min while a farinogram was obtained. Then the kneaded rice paste was heaped compactly into a 5-cm aluminum weighing dish, allowed to stand 4 hr at room temperature, and struck level with a knife. A few drops of edible oil were spread on the cut surface to prevent sticking of the plunger, and several measurements were made on each gel with the Bloom Gelometer.

RESULTS AND DISCUSSION

Developmental Aspects

Whole Method. Using the method as a whole, the following variables were examined: different operators, methods of placement of the cooked rice on the Instron platform, water to rice ratios, and cooling time.

The first sets of samples run were significantly operator-dependent, but some additional effort at standardization definitely removed this factor. There seems to be no reason why reasonable care cannot be used to make stickiness results operator-independent (ie, different operators).

Both the piled and single-grain thickness configurations of the 2-g sample on the platform gave satisfactory results. In most of the work reported, the piled configuration was used because extra work was required to flatten the samples, especially with the stickier rices. With less sticky samples, time was actually saved by using the flat configuration because the anvil could be positioned closer using the fast speed. Packing the rice on the platform was found to increase the stickiness value. Variations in manipulation at this point of the test are a definite source of error.

The effects of the water to rice ratio and the cooling time on stickiness value were investigated together in the same experiment. Within the ranges examined, both time and water effects were significant. Increasing cooling or standing time caused a small linear increase in the stickiness value, which indicates that a standard cooling time should be used and that small deviations can be ignored. Increases in cooking water had a positive curvilinear effect on stickiness values, which also indicated the need for standardization. The mean stickiness values for water levels are shown in Table I. The water and time interactions became significant at the 6% probability level, showing that the amount of the time effect may change with different water levels and vice versa.

The effect of changes in the water to rice ratio on the random variation at each water level was later determined from these same data (Table I). An increase in the water to rice ratio from 1.25 to 1.50 reduced the variation by 50% in this set of samples. The 1.75 ratio also varied less than the 1.25 ratio that was our standard. The use of the lower water level tended to compress the least sticky rices near the zero level. Perhaps a higher water level would tend to bring out differences among long grain varieties.

Each part of the method was then examined separately for the amount of variation it contributed to the whole, starting at the Instron and working backwards.

Instron Variability. To test the variation attributable to the Instron itself, 1-g samples of pure glycerine were placed on the platform and tested for stickiness as usual, except that the 10-sec hold was eliminated. This experiment was followed by running samples of cooked rice and water slurried in a blender to simulate a semihomogeneous rice material. Because of their extreme stickiness, the slurry samples required high dilution. Results are shown in Table II. Coefficients of variation are quite low for the pure samples and not excessive for the semihomogeneous rice. The Instron itself seems to vary less than 5%, the sampling error to add a couple of percent, and the lack of complete uniformity in the rice slurry along with slight weighing variations to add a few more.

Handling Variability. The amount of variation attributable to handling the samples was determined by placing 1-g samples on the platform and running the Instron test five times without removing the sample. Three samples, drawn from the top, center, and bottom of each beaker, were used. A similar series was then run, but each sample was removed, the platform cleaned, and the same sample replaced and retested. The first value for each set was the value of the fresh sample and represented the standard testing procedure. Means, standard deviation, and coefficients of variation were

TABLE I
The Effect of Water to Rice Ratio on the Stickiness Value, and the Variation at Each Level for Calrose Rice[a]

	Water to Rice Ratio[b]					
	0.75	1.00	1.25	1.50	1.75	2.00
Water (g)	6	8	10	12	14	16
Stickiness value, $\bar{x}$ (g·cm)	3.35	3.68	3.51	3.61	3.85	4.27
s (g·cm)	0.52	0.51	0.49	0.23	0.35	0.78
Percent $s/\bar{x}$	15.6%	13.8%	13.8%	6.4%	9.1%	18.3%

[a] Means ($\bar{x}$), standard deviations using $n - 1$ degrees of freedom (s) (where $n = 8$), and coefficients of variation (percent $s/\bar{x}$) were calculated separately for each water level. Water effects are removed, but time effects are included in these values. $\sqrt{}$ Mean square of residual after both water and time effects were removed was 0.43 which is equivalent to an overall s, and compares with a large set run at our standard ratio, 1.25 ($n = 18$, $df = 17$) whose $s = 0.51$.
[b] Eight grams of rice was used for each, with water varied as shown.

TABLE II
Variation in Stickiness Values for Homogeneous Materials[a]

Sample	n	$\bar{x}$ (g·cm)	s (g·cm)	Percent $s/\bar{x}$
Glycerine[b]	4	1.88	0.07	3.7
Glycerine[c]	8	1.84	0.10	5.4
Rice slurry[d]	11	0.87	0.10	11.5

[a] Mean stickiness value ($\bar{x}$), standard deviation (s) using $n - 1$ degrees of freedom, and coefficient of variation (percent $s/\bar{x}$) of n replications are given.
[b] Single samples of glycerine were each tested four times without removing from platform. Values shown are averages of the values for eight such runs.
[c] Eight glycerine samples were tested one time each.
[d] Eliminating weight variation by regression of stickiness on sample weight produced a standard error of 0.07 (in place of $s = 0.10$ shown here).

calculated for each set, omitting the first values of each set (set $n = 4$), which were computed as a separate set ($n = 6$). The average of the coefficients of variation for the samples tested without removal was 4%, and for those removed and replaced 16%. That for the standard test values was 21%. The first series did not include variation due to application nor to use of separate samples. The second series did not include variation due to separate samples but included application and handling. The third included variation due to both application and separate samples. The coefficient of variation compares well with the glycerine results, indicating again a low basic variability in the instrument (4%), with variability added from placement (12% more in this test), and from using fresh samples (5% more in this test).

Sample Size. Rice cooked in the standard manner was tested using various sample sizes from 2 g down to single grains. The change in coefficient of variation is shown in Table III. The standard deviation remained approximately constant while the mean increased with increasing sample size. Thus, the amount of grain to grain variation was large as a percentage of the stickiness value in smaller samples and, as would be expected, became less of a factor as sample size increased, but at a reduced rate of change. It is possible that a major variation exists among grains, and that the larger sample size, with the greater number of grains, simply increased the sample homogeneity.

Cooking Dynamics. The cooking procedure can increase the variability between stickiness values either by augmenting the actual variation between grains inherent in the raw rice or by causing segregation between larger samples, for example, by allowing stratification of water to rice ratios in the beaker during cooking, or some similar segregation between beakers.

To investigate the moisture differences within the same beaker, 2-g samples cooked by the standard method and taken sequentially from top to bottom of a beaker were analyzed. The moisture contents of eight 1-g samples of the raw rice (Calrose) were determined for comparison. The average moisture of the cooked samples was 61%, but the individual samples ranged from 56.6 to 65.4% for a spread of 8.8% among samples ($s = 2.8\%$). Regression from top to bottom of the beaker gave a decreasing moisture slope of 0.67, but the standard error around the regression line was still 2.3% (compared to $s = 2.8\%$), and samples from the center of the beaker showed just as much deviation from the average as the ends. Five more beakers were similarly tested, with the same results. On the other hand, the samples of the original raw rice ranged from 11.8 to 12.0% moisture for a spread of only 0.2% ($s = .08\%$).

An attempt was made to determine the moisture on samples after they were run on the Instron. A series of 2-g samples taken from top to bottom of four beakers was tested but did not correlate with stickiness. Such routine correction of each sample for moisture does not seem feasible or effective.

To test the effect of the intensity of cooking on the moisture slope, three beakers were steamed at different burner flame heights and sampled for moisture as before. To observe visually the effects and general cooking action, it was necessary to steam additional beakers in a smaller glass outer container. The rate of steaming for different-sized containers was standardized based on the amount of water lost per minute per unit surface area of the container. In this way, it was possible to get some idea of the dynamics occurring at different flame heights in the opaque steaming pan from which moisture samples were drawn.

With the very low flame, the water remains in the bottom, and the sample is wet at the bottom and drier at the top. At medium flame, the moisture is driven from the bottom of the sample to the top, which becomes wetter, and a small amount of moisture is lost. At high flame, the moisture is driven off the top, which becomes drier than the bottom since it is more exposed to the atmosphere. At all flame heights, the water in the steaming container is boiling, but heat transfer is greater at more vigorous boiling rates. Suspending the beaker away from the screen and sides by rubber inserts did not reduce the heat transfer, so that the action seems to be caused by the contact of the steam. It would be possible to adjust the boiling rate to remove the slope, but the variance would still be large. Of the two flame heights that produce a horizontal or zero slope, the lower is probably to be preferred, since it dries the sample less. It is certainly evident that attention should be paid to whatever method of heat transfer is used. Mixing the sample after cooking, which is recommended in some literature methods, could be used to remove some of the remaining variance, but it is very difficult to do with sticky samples.

A large sample of Calrose was cooked by the oven method of Batcher et al (1963a); ie, 100 g rice, 250 g water, 176° C oven, 40 min covered, 5 min open in oven. It was found to be much dryer at the top and edges, with the overall texture much less uniform than with our samples. It seems the large sample, the mixing, and the large number of replications (panel members) were enough to overcome the lack of uniformity in tests described in the literature. It is also noteworthy that the device recommended by the FAO for cooking rice for testing consists of an oil bath kept at 100°C (Gariboldi 1973).

Improvements of the Method. The purpose of the method was to detect differences in stickiness and to measure stickiness levels. A difference of 1 g·cm was found between the nearest sticky and nonsticky rices investigated in conjunction with this work (Fellers et al 1983). The Instron method as first run, however, taking eight samples from one beaker in sequence, required a difference of 1.4 g·cm between rices to distinguish them as different (using Calrose, at the 90% probability level). Therefore, even some of the sticky and long grain rices may not have been identified as significantly different based on that method. Adoption of the balanced design described in the standard method, which includes selecting from several beakers, improved the precision considerably. When the standard method was carefully applied to one lot each of twelve different rice varieties (Fellers et al 1983) a difference of only .8 g·cm was needed between means of sticky varieties such as Calrose, and a difference of .3 g·cm was required between the long grain rices for detection as different (Tukey's test using pooled variances). In this application the precision was high enough to distinguish not only between the sticky and nonsticky rices but also between subgroups within the sticky rices (Calrose $s = .3$). In routine use, however, the variance of the standard method using 1.25 water to rice was not constant enough to distinguish smaller differences reliably. The detectable difference calculation depends not only on the amount of the variance (s^2) but also on its variation when the method is put to routine use. For small differences to be detected, the variance must be not only low but consistent (the variance of the variance must also be low). Thus the goal of the potential improvements described here (optimum water, uniform cooking and handling) was not only to reduce the variance (Calrose $s = .2$ in Table I) but also keep it constant enough so that the smallest differences may be detected routinely. The Instron is precise enough to show these differences, but the user must present a consistent sample to the instrument for the differences to be detected as significant. The characteristics of the material being measured, the basic precision of the method, and the care with which the method is applied all influence the power of the method in this regard. It is recommended that the user test the method initially and monitor the results in routine use.

TABLE III
The Effect of Sample Size on the Stickiness Value and the Amount of Random Variation between Samples[a]

Sample Weight (g)[b]	No. of Kernels[b]	n	$\bar{x}$ (g·cm)	s (g·cm)	Percent $s/\bar{x}$
2.0	40	18	3.06	0.51	17
1.0	20	6	2.46	0.50	20
0.5	10	6	1.54	0.36	23
0.25	5	6	1.30	0.30	23
···	1	6	1.34	0.47	35

[a] Mean stickiness value ($\bar{x}$), standard deviation using $n-1$ degrees of freedom (s), and coefficient of variation (percent $s/\bar{x}$) of n replications are given.
[b] Samples up to 10 grains were counted. Larger samples were weighed, and then placed in a layer one grain deep on the platform for this series.

Interpretation of the Stickiness Units

The adhesive character of a substance is best described theoretically by Stefan's equation (Banks and Mill 1953, Bikerman 1947), which relates stickiness to coefficient of viscosity. In early work on adhesive bonds, it was quickly discovered that many other factors such as cleanliness of the bonding surface, uniformity of application, homogeneity of the adhesive (free from air bubbles), were more important in determining the actual bond strength than the natural adhesiveness described by viscosity. As a result, adhesion technology is now based on a number of complicated empirical formulae relating together a number of factors which have only an indirect relation to basic stickiness. For our purposes, it is better to examine the actual test procedure itself to determine the proper stickiness units to use.

It has been said that the Instron lends itself better to direct physical interpretation of results than other similar machines, because of its strictly perpendicular motion (Bourne 1968). Because the crosshead moves at a constant rate it appears that either work (force × distance) or impulse (force × time) may be determined. However, the units for both work and impulse are defined in physics as being obtained under strict conditions which are not met by the rice sample. It is the anvil which moves perpendicularly through a distance while subject to an applied force (caused by the rice) and upon which the valid measurements are made (by the compression cell). The conversion of the complex forces in the rice sample to the simple force component against the anvil is probably incomplete and must vary among samples. Yet the force on the anvil probably is the most direct measure of the adhesion effect actually occurring during the test of a particular rice sample. Thus, the effect should be expressed in units involving cumulative force.

Since work is obviously done on the rice by the anvil during compression, expressing the reverse adhesive resistance in work (force-distance) units seems appropriate. Work is also instinctively easier to visualize in terms of the test, although impulse is probably theoretically closer to adhesion, since impulse and viscosity are both momentum phenomena. We see no reason why the stickiness values cannot be reported in g·cm work if the limitations to interpretation are kept in mind.

Gelometer and Farinograph

Model rice samples having a range of different stickiness properties were tested in the Bloom Gelometer and Brabender Farinograph, including some rices that were heat treated to reduce stickiness. Both Gelometer gel strength and Farinograph peak time were lowest for the untreated sticky rice, intermediate for the treated sticky rice, and highest for the long grain. Farinograph peak height and final height values did not show a clear trend. Thus, gel strength and peak time seem to reflect stickiness and either might be used as the basis of a test, whereas the peak and final height seem unsuitable.

CONCLUSIONS

The Instron method described here measures surface stickiness more directly than the Gelometer or Farinograph methods, although either of the latter two could be useful to follow the stickiness of the whole sample. The Instron method is precise enough to distinguish easily between long grain and sticky varieties, and may be able to distinguish several levels among sticky varieties. It may not be precise enough to distinguish small differences consistently without improvement.

Variation due to the instrument itself is much less than that due to the sample and its handling. The method of running the test avoids the errors due to inertia, mentioned by Voisey (deMan 1976), but allows variable relaxation under compression, which may contribute to error.

Quantitative results suggest the following modifications to reduce random variability significantly and allow finer differences to become distinguishable. Increase the water to rice ratio from 1.25 to 1.5; increase the size of the test sample; develop a very reproducible method of placing the test sample on the platform; and give special attention to the cooking. Mixing the cooked rice before sampling, which may be appropriate in many cases, would eliminate much of the within-beaker variability. The lower water to rice ratio might be advantageous if sticky varieties are to be mixed after cooking. Additional smaller improvements can be obtained by strict control of the temperature, humidity, and times of cooling and manipulations, but this effort should not be at the expense of the number of replications, which also contributes to precision.

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