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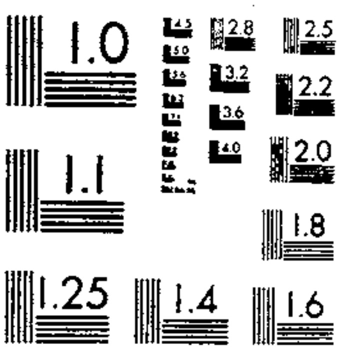

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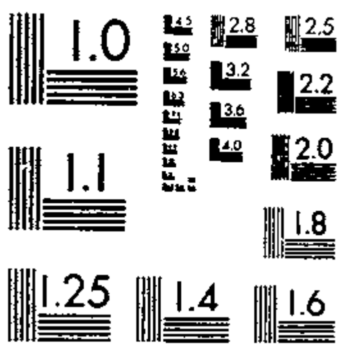

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QUALITY EVALUATION STUDIES OF FOREIGN AND DOMESTIC RICES

by
J. E. Simpson, C. R. Adair, G. O. Kohler, E. H. Dawson,
H. J. Deobald, E. B. Kester, J. T. Hogan,
O. M. Batcher, and J. V. Halick

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In the beginning of this project, Foreign Agricultural Service selected and supplied 600 rice samples from the markets of 34 countries, and Agricultural Marketing Service graded the samples according to U.S. rice standards.

In the second part of this project, four Divisions of Agricultural Research Service have cooperated to determine the physical and chemical properties of the rices. The assistance of and helpful suggestions from the following personnel are particularly acknowledged:

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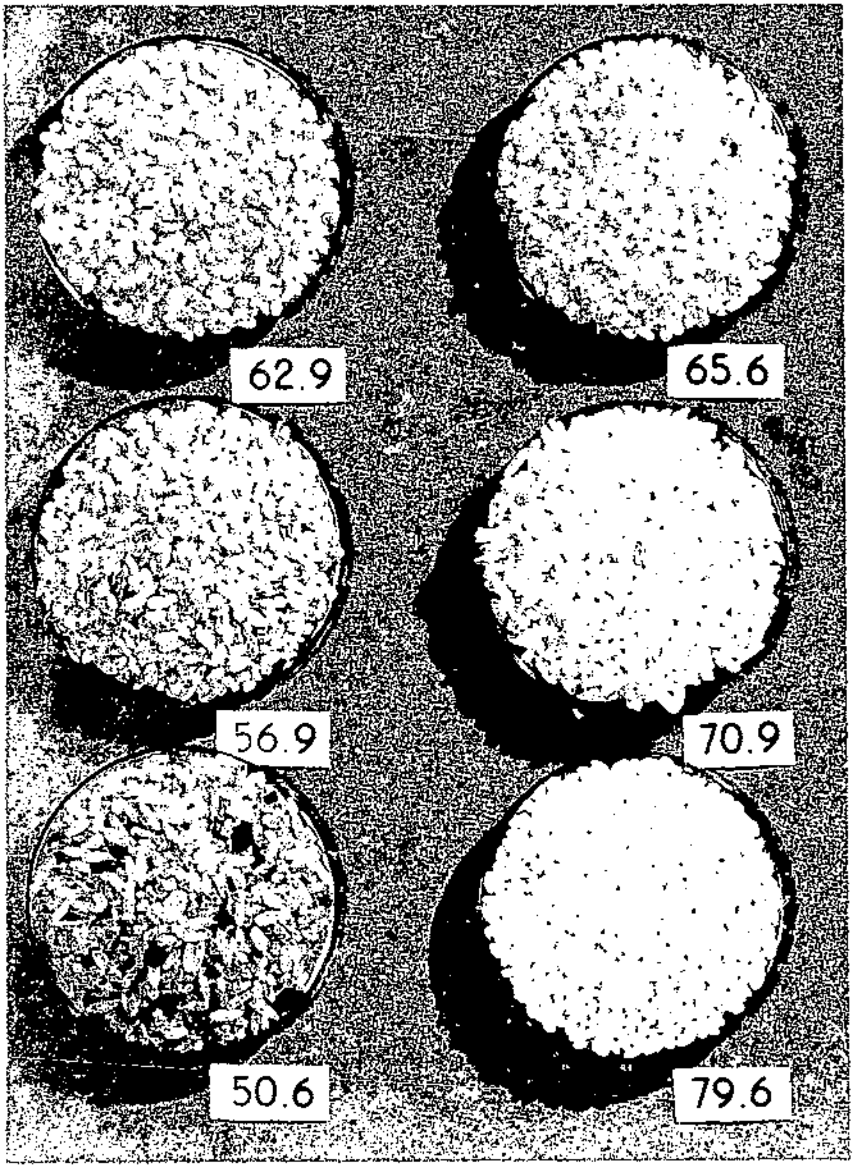

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By J. E. Simpson, *Office of Administrator;* C. R. Adair, *Crops Research Division;* G. O. Kohler, *Western Utilization Research and Development Division;* E. H. Dawson, *Human Nutrition Research Division;* H. J. Deobald, *Southern Utilization Research and Development Division;* E. B. Kester,[1] *Western Utilization Research and Development Division;* J. T. Hogan, *Southern Utilization Research and Development Division;* O. M. Batcher, *Human Nutrition Research Division;* and J. V. Halick,[2] *Crops Research Division*

PART 1.—OBJECTIVES AND SCOPE

Introduction

A cooperative project between the Agricultural Research Service (ARS) and the Foreign Agricultural Service (FAS) was initiated in 1957, as a first step toward defining the kinds of rice that move in international trade and the kinds preferred by consumers in importing countries. The primary goal of this joint investigation was to establish some basis for comparing the competitive position of a particular rice in a particular market. Lack of international grades in rice and of correlation of individual grading systems has made this comparison difficult up to the present time.

A second purpose of this cooperative project was to obtain information that would aid rice-production research agencies in developing new strains and varieties of rice especially adapted to the requirements of overseas markets, thus assisting in directing rice of the most desired types into each significant marketing area.

A third objective of the investigation was to develop basic knowledge of the interrelationships between chemical composition and physical characteristics as affecting processing and cooking characteristics.

This project has embraced a two-part study on nearly 600 milled or partially milled foreign rices obtained by Foreign Agricultural Service during 1958 and 1959 in 33 countries, representing 15 net exporters and 18 net importers. The first part of this study was based upon analyses by the Agricultural Marketing Service (AMS) laboratory at New Orleans to evaluate the foreign rices in terms of U.S. grade standards. That part of this study has been reported in "Analysis of Selected Varieties and Grades of Rice Moving in World Trade," (*39*)[3] which discusses and summarizes the grading reports.

The second part of this investigation, reported herein, was done by the Agricultural Research Service (ARS), in which detailed chemical

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[1] Deceased.
[2] Resigned.
[3] Italic numbers in parentheses refer to Literature Cited, p. 184.

and physical quality evaluation studies have been conducted on these foreign rices. The ARS studies were made by four Divisions: the Western Utilization Research and Development Division (Albany, Calif.), the Southern Utilization Research and Development Division (New Orleans, La.), the Crops Research Division Laboratory at the Rice-Pasture Experiment Station (Beaumont, Tex.), and the Food Quality Laboratory of the Human Nutrition Research Division (Beltsville, Md.). Samples of U.S. rices (long-, medium-, and short-grain) were included for comparative purposes. Both objective and subjective test methods were used in these studies.

Samples Obtained

Representatives of the Foreign Agricultural Service were responsible for obtaining and shipping the samples from the foreign sources. Samples were taken from stocks of rice in storage for export, from shipments enroute, from shipments in storage at ports of destination, and from local stocks of indigenous rice, including samples from retail market outlets. The FAS report (*39*) gives the conditions for sampling, and information concerning: Points of origin; local or trade names of varieties; grades at points of origin (if a system of quality grading existed); years grown; special processing (i.e., parboiled, glazed, etc.); whether grown as upland or irrigated rice; whether the variety was a major one in export or domestic markets; quality factors and classes as reported by AMS grading service.

Representative milled or partially milled samples of about 3 pounds each were obtained under standard sampling procedures. Each sample was divided into two or more parts; one part was forwarded to the Grading Service Laboratory (AMS) at New Orleans for evaluation by U.S. grade standards, and the other part or parts were sent to the specified ARS laboratories. The samples were packed in polyethylene bags, sealed with tape, and shipped in heavy canvas bags. Shipment was by air to minimize changes due to aging, temperature variation, moisture fluctuation, insect infestation, and mishandling. Samples were received in good condition, with only a few exceptions.

The numbers of samples received from each of the 33 foreign countries represented in this study, totaling 557 samples, were:

Country	*Number of samples*
Africa, South	5
Argentina	11
Australia	1
Brazil	16
Burma	57
Ceylon	10
Chile	48
Colombia	5
Ecuador	6
Egypt	5
El Salvador	2
France	6
Germany, West	15
Ghana	1
Greece	16
Guatemala	2

Country	*Number of samples*
India	66
Indonesia	32
Iran	15
Italy	9
Ivory Coast	2
Japan	84
Korea	12
Mexico	9
Nigeria	1
Pakistan, East	12
Pakistan, West	18
Peru	10
Philippines	10
Portugal	5
Spain	5
Thailand	54
Turkey	7

Performance of Testing

The Crops Research Laboratory at the Rice-Pasture Experiment Station received a part of every sample. Portions of over half the samples—representing most of the countries and all of the grain types—were sent to the Food Quality Laboratory of the Human Nutrition Research Division for cooking and related tests. In general, the Southern Utilization Research and Development Division made determinations primarily on the long-grain samples, and the Western Utilization Research and Development Division was primarily concerned with evaluating short-grain rices, with both laboratories being involved in evaluating the medium-grain samples.

Quality Characteristics Determined

For the purpose of evaluating the quality characteristics which are distinctly apart from the presently recognized marketing characteristics, this presentation of the studies made by the four Agricultural Research Service laboratories is limited to the following numerically valued tests and measurements:

- Physical Measurements:
  - Kernel Length
  - Kernel Width
  - Broken Kernels
  - Color
- Thermal and Chemical Reactions:
  - Gelatinization Temperature
  - Heat Alteration
  - Water Uptake and Sedimentation (at 77° C. and 82° C.)
  - Alkali Spreading and Clearing
- Chemical Determinations:
  - Lipid Content (Surface and Total)
  - Protein (Nitrogen)
  - Moisture
  - Crude Fiber

Chemical Determinations—Continued
- Ash
- Starch Content (Total, Amylose, Amylopectin)
- Starch-Iodine-Blue Value

Palatability Characteristics (After Cooking):
- Appearance
- Cohesiveness
- Tenderness
- Flavor.

It is emphasized that the analytical values determined in these investigations depict the measurements made on these particular samples. Many of these values are dependent on the degree of milling, the grading system used, handling and storage conditions, or other factors. In other words, the results reported on these samples do not necessarily reflect the true inherent characteristics based on whole-grain rices harvested at about the same moisture content and milled and stored under comparable ideal conditions. However, these reported values are believed indicative of the quality of the rices moving in these market channels at the time.

The choice of tests for evaluation of rice quality has been based on a careful study of the findings reported by rice researchers in the technical literature, and on a knowledge of the elements used in U.S. grading laboratories to determine market quality.

Kernel dimensions, particularly *length*, have long been prime characteristics for establishing quality of rices. A study of these characteristics, plus a consideration of the amounts of *broken kernels* present, therefore has been included in this investigation.

The *color of rice* samples submitted in this examination of world samples varied over a wide range, as will be seen from the frontispiece. Color is important in the grading of rice, since whiteness is a widely recognized criterion of quality. For this study, a sensitive colorimeter was used for evaluating color because subjective methods do not show fine gradations and introduce an operator variable. The value of this instrument had been demonstrated in other rice investigations by researchers at the Western Utilization Research and Development Division (*21*, *22*, *40*).

The principal chemical constituent of rice is *starch*. Reagents or other factors that produce discernible changes in starch will therefore effect related changes in the intact rice grain. Similarly, differences in the chemical and physical behavior of rice that innately pertain to the different types of starch present will be reflected in the rice itself, as their proportion differs from variety to variety. Rice starch is composed of two molecular types: A large branched molecule called *amylopectin*, and a smaller unbranched or "straight chain" molecule called *amylose*. Because of the structural difference in these molecules, they respond differently to treatment with water, iodine, alkali, and other reagents. Common rice varieties contain both types of starches, but the glutinous rices contain only small amounts, if any, of amylose starch. With reference to American rices, it is known that a general relationship exists between grain type and cooking quality. According to Jodon and de la Houssaye (*23*), the characteristics of cooked rices vary from "very sticky" to "flaky," the short- and medium-grain varieties being somewhat sticky, whereas the long-grain varieties are usually flaky. Thus the question arises as to whether correlation of cooking quality should be made with grain type or with chemical composition which usually varies with grain type. Williams and others (*45*) found, in studies of U.S. varieties, that as a general rule, the long-grain types had higher amylose content. Toro and Century Patna were exceptions in this regard, and when cooked they are more sticky than other long-grain rices. These Toro and Century Patna rices, despite their shape characteristics, have low amylose content, indicating that *amylose may be an important factor* in determining the processing characteristics of rices. As a corollary, one could say the same of *amylopectin,* and of the *ratio between the starch constituents.* Therefore, for this study, percentages of total starch, amylose, amylopectin, and ratio of amylose to amylopectin were measured or calculated.

The property of *water uptake by rice at 77° C. and 82° C.* has been measured because it has a bearing on cooking and processing quality (*16*). The same is true of loss of solids into the cooking water (*20*). Sticky rice varieties lose more solids into cooking water than do the flaky types. For example, certain long-grain domestic varieties such as Rexoro and Bluebonnet are preferred for certain commercial processed products because sloughing of solid matter with these rices is minimal.

Gelatinization temperature is related to water uptake, according to findings reported by Halick and Kelly (*16*). Short- and medium-grain rice varieties having low gelatinization temperatures absorb more water than do most of the long-grain types. Here again, Toro, a long-grain rice with a low gelatinization temperature, was similar to the short- and medium-grain rices in water-uptake behavior. Two long-grain varieties with high gelatinization temperatures, Early Prolific and Century Patna 231, absorbed less water than did any other domestic rices.

The starch-iodine-blue value was originally used by Roberts (*40*) in examination of parboiled rice samples. It was later found (*17*) that this method could be used to determine varietal differences using rice that was not parboiled. The test is indicative of the amylose soluble under the conditions of measurement, and has been shown to have a close correlation with total amylose content (*45*). For this reason, the iodine-blue value is another measure of cooking behavior. The test is run at 77° C., which is above the gelatinization temperature of many short-grain varieties but below that of such long-grain varieties as Century Patna 231. This test, therefore, helps to distinguish rices from that standpoint because during gelatinization amylose appears to solubilize, and in turn participates in the iodine reaction.

The alkali spreading and clearing test was selected because investigations by Little, Hilder, and Dawson (*31*) showed that differences in response to this reagent, of varieties and lots of rice, paralleled in general the differences in subjective assays of cooking quality. Highly significant relationships were found between scores for cohesiveness of cooked samples and the extent of spreading and clearing of rice grains immersed in dilute alkali.

The heat alteration value (*30*) is a procedure for predicting cohesiveness characteristics of rice varieties when cooked. It involves microscopic examination of finely ground rice after being treated with water at 60° C. Rices that are fluffy or flaky after cooking show little change in the granules when this test is applied, whereas rices that clump or show pronounced cohesiveness become more or less gelatinized.

The attributes of *appearance, cohesiveness, tenderness, and flavor of cooked rice are the final criteria of cooking quality.* The experimental rice-cooking procedures developed at the Human Nutrition Research Division, Agricultural Research Service, Beltsville, Md., have been found very suitable for the subjective evaluation of these qualities of rices (*5, 6*).

Total lipid content affects nutritional and other properties. Assay of *surface lipids* was adopted because it had been demonstrated in tests of Zenith and Rexark rices (*3*) that the amount of fat extracted from whole milled rice was in linear relationship to the amount of bran removed up to about six percent of brown rice starting material. It was further shown that for a given variety, the relationship between the percentage of bran removed and the percentage of fat remaining on the milled rice is constant from year to year. Those studies indicate that the fat removable from the surface of milled rice is a reliable measure of the amount of inner bran and aleurone layer remaining.

Protein content is important from a nutritional standpoint. The amino acids in rice, which occur combined as protein, have been investigated at Louisiana State University Biochemistry Department (*35, 36*)[4] with respect to variation of kind and amount among different rice varieties. The location where the rice was grown was found to have an important bearing on the content of individual amino acids. Removal of bran layers, as in milling, causes a decrease in the protein content of rice, and also in the essential amino acid content. From results on rice milled to different degrees, it was concluded that the nature and distribution of protein within the grain was not uniform. Moreover, an increase in the nitrogen or protein content of a particular variety, from whatever cause, did not necessarily reflect an improvement in the essential amino acid pattern of the grain. All rice samples examined in the present study were analyzed for percentage of total nitrogen, and protein was computed by multiplying the figures by the appropriate factor.

The factor of *moisture content* is paramount in determining maintenance of quality in rice during storage, because its level controls the rate of deterioration and infestation of the grain. Commonly accepted moisture contents for "safe" storage are 13 percent for less than 6 months' storage, and 12 percent for long-term storage (*10*). When moisture exceeds 15 percent, rice is automatically classed as "sample" grade in U.S. grading laboratories. Other quality factors may be adversely affected by excessive moisture. The value of moisture content in rice analysis, however, is in computing percentage of other constituents such as starch and protein to the dry basis.

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[4] Kymal, K., 1955. VARIATION IN AMINO ACID CONTENT OF RICE VARIETIES. [Ph. D. thesis. La. Sta. Univ., Baton Rouge.]

Fiber and ash, minor constituents of rice, apparently are of relatively little importance as quality factors. They were determined on a representative number of samples to ascertain whether unusual differences would be found among the samples collected throughout the world. Investigators at the Southern Utilization Research and Development Division found that cultural environment influenced the ash content of white milled rice (*33*). In this study of world rices, correlations of fiber and ash contents with other factors were not evaluated.

PART II.—METHODS AND PROCEDURES

Physical Measurements

Kernel Length and Width

Kernel length and width of milled grains were determined by measuring (in millimeters) 20 whole grains (full-length grains free from breakage), selected at random from a small representative sample, and calculating mean values. The image of the rice grains to be measured was reflected on the screen of a modified photographic enlarger and magnified exactly 10 diameters. The accuracy of the magnification was checked by placing a transparent millimeter scale in the field and measuring the enlarged image.

Kernel length was classified as:

Long (L)—6.16 mm. and greater.
Medium (M)—5.16 mm. to 6.15 mm., inclusive.
Short (S)—5.15 mm. and less.

Long-, medium-, and short-grain rices are illustrated in figure 1.

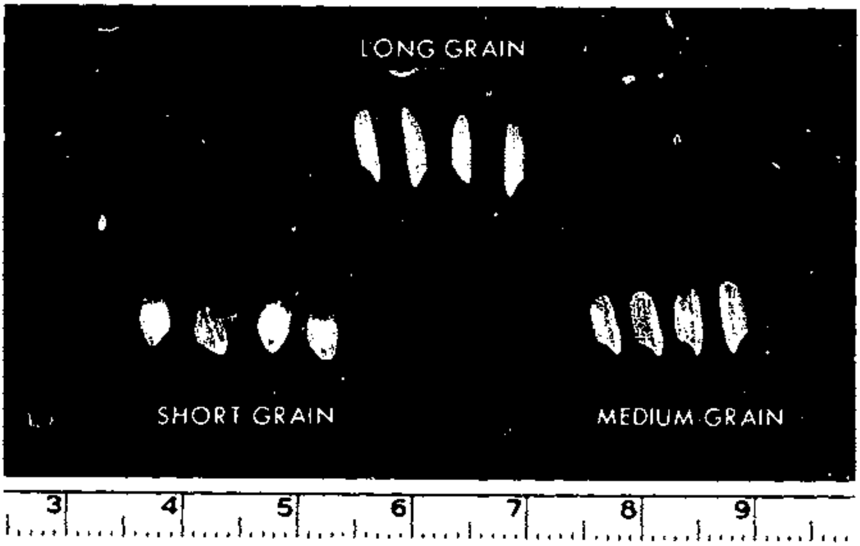

FIGURE 1.—Samples of long-, medium-, and short-grain rices.

Broken Kernels[5]

The percentage of *broken kernels* was determined on a weight basis by analyzing a 100-gram sample of the milled rice. Broken kernels are

[5] Percentage of broken kernels for all samples was determined by the AMS Grain Grading Service Laboratory, New Orleans, La.

defined as pieces of kernels that are less than three-fourths the length of a whole kernel, and fragments of split kernels. Broken kernels were separated out by using standard sieves and sizing plates, in accordance with the methods prescribed by the U.S. Department of Agriculture, Agricultural Marketing Service, for determining the grade of milled rice samples (*1*).

$$\text{Percentage of broken kernels} = \frac{\text{total weight of broken kernels}}{\text{weight of sample}} \times 100.$$

Kernel Color

Kernel color was determined with a Color and Color-Difference Meter (such as a Gardner or Hunter) (fig. 2) standardized on the "L" scale with a light-yellow standard (C–LY–1091–58), values L=78.4, $a_L = -1.6$, $b_L = 22.9$ (*12*). Glass cells (optical glass base, 82 mm. in diameter, and 38 mm. in height) were filled with the rice, leveled with a spatula, the cells placed over a large aperture (2¼-inch diameter), and readings made.

The average of four determinations, for each of the three color components (L, a_L, and b_L), rotating the cell clockwise for 90 degrees between replications, was the value used. Only the "L" (or lightness value) was evaluated statistically.

FIGURE 2.—Measuring the color components of rice by the Gardner Color and Color-Difference Meter.

Thermal and Chemical Reactions

Gelatinization Temperature

A slurry was prepared by mixing 100 grams of rice flour (prepared by grinding in a No. 3 Wiley mill to pass 0.5 mm. screen) and 250 ml. of distilled water in a Waring Blendor for 1.5 minutes. The slurry was transferred to the Amylograph (research model manufactured by the Brabender Corp.) (fig. 3) using 150 ml. of additional water to wash quantitatively from the blendor. The Amylograph mechanism was started with the cooling coil solenoid switch in the "up" position and the slurry allowed to heat to 30° C. with gear in the "N" position. The chart was then adjusted to a zero minute marking, the gear switch placed in the "U" position, and heating continued at the controlled rate of 1.5° C. per minute. The temperature of the slurry at which the initial increase of viscosity occurred was recorded as gelatinization temperature (*15, 16*).

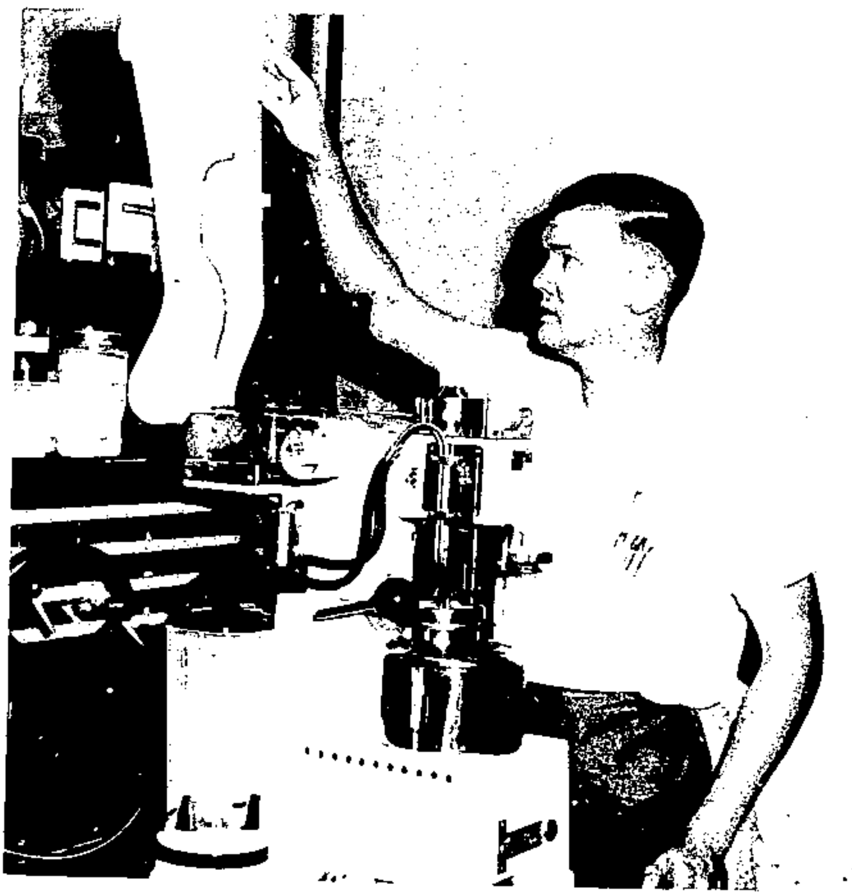

FIGURE 3.—Amylograph for determining gelatinization and pasting characteristics of ground milled rice over a controlled temperature range.

Heat Alteration

Five grams of rice was soaked 2 hours in 25 ml. of 1 percent sodium chloride solution at 38–40° C. The mixture was made up to 195 ml. with 1 percent salt solution at room temperature, and blended for 15 minutes at medium speed (controlled by a Powerstat Variable Transformer, Type 116, set at 70) in a Waring Blendor. The slurry was suction-filtered through No. 589 Blue Ribbon S&S filter paper, washed with 300 ml. of distilled water, and dried in air at room temperature. The dried sediments of most samples formed a moderately brittle cake, which was broken up and kept in stoppered vials under refrigeration until used. When the slurries did not filter well, as in the case of some severely parboiled samples, they were centrifuged and the solid matter was washed and centrifuged repeatedly. After the final washing, the material was dried to a cohesive cake that could be easily redispersed in water (*30*). (See fig. 4.)

For each replication, 0.25 gram of rice powder was dispersed in about 5 ml. of water, heated 30 minutes, and stirred constantly, in 65 ml. of distilled water held at 62° C. in a constant-temperature oil bath (fig. 4). A 2-ml. portion of the suspension was diluted to 15 ml. with water at room temperature, a drop of the dilution placed on a microscope slide, covered, drained of excess liquid, and sealed with petroleum jelly. The procedure was repeated at least once for

FIGURE 4.—Equipment used in preparing rice powder for the heat alteration test.

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each rice lot. Controls consisted of rice powder from the original sample, soaked 30 minutes in water at room temperature and mounted on slides in the same way as the heated samples.

A Bausch & Lomb binocular research microscope (with positive or dark contrast phase accessories and a magnification of 970 diameters) was used to evaluate the effects of the treatments on the starch (fig. 5). As the slide was moved across the microscope stage, the first 100 granules passing through a specified portion of the field of vision were counted and classified in one of four categories, illustrated in figure 6, and characterized as follows:

1. Granules unaltered (angular, luminous, and without definite

FIGURE 5.—Phase contrast microscope and pulsing xenon arc lamp used in heat alteration test.

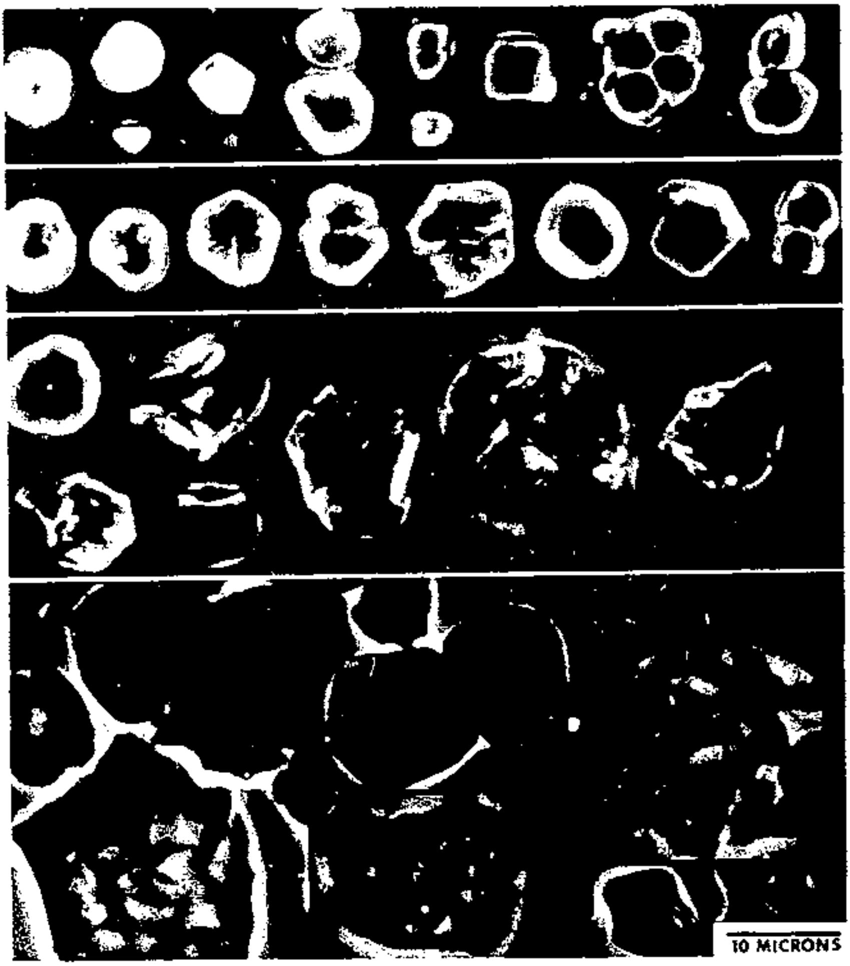

FIGURE 6.—Alteration of starch granules from different rice varieties when heated at 62° C. (heat alteration test).

hilum although often appearing slightly darker[6] in the center). Starch from all unheated samples was of this appearance, as was most starch from treated samples of some varieties.

2. Granules slightly altered (darkened,[6] cracked, or striated from

[6] In describing starch granules as partly or completely darkened, the intention is to portray an apparent decrease or loss in luminosity as seen in dark contrast phase illumination, which seemingly coincides with loss of birefringence in polarized illumination. Starch altered by the heating treatment no longer appears crystalline, but is a semitransparent gelatinous body. This starch is white or colorless in ordinary bright-field microscope illumination, and appears dark in phase contrast only because of the quality of light transmitted by this instrument. A mass of "darkened" granules suspended in water constitutes a whitish or translucent paste.

the center outward, but luminous in half or more of their diameter, perhaps slightly swollen). Granules of this type occurred in heated samples, rarely in unheated samples.

3. Granules moderately altered (more than half darkened, usually swollen, with luminuous areas in the form of blocklets, striations, or uniform or patterned rims or convolutions on the surface of the otherwise darkened structure). Moderately altered granules occurred only in heated samples.

4. Granules greatly altered (slightly to greatly swollen, completely darkened, and lacking luminous portions, but definitely outlined and surrounded by a lighter halo. Markings suggestive of those described in category 3 were commonly present, but were darker than the major portion of the granule.) Greatly altered granules were found only in heated samples.

For each lot of rice, the number of granules in each category was multiplied (or weighted) by the category number; the weighted values were totaled and divided by 100 to give a "darkening index." Darkening indexes of unheated replications (controls) were deducted from the darkening indexes of heated replications to give "heat alteration values." In the case of parboiled samples, it was necessary to evaluate darkening indexes of unheated controls along with heat alteration values.

The heat alteration value of a sample is then the difference between the darkening index of 100 untreated starch granules and that of 100 starch granules from the same sample after heating 30 minutes in water at 62° C. The darkening index of a nonparboiled sample receiving no heat treatment is low (1.0–1.2, rarely up to 1.4), whereas the darkening index of a heated sample can be any value from 1.0 to 4.0; the darkening index of a parboiled sample receiving no additional heating treatment may be any value from 1.2 to 3.9 or 4.0. Thus, heat alteration values could be anywhere between 0.0 and 3.0. In a regular milled rice sample, the heat alteration value is inversely related to the gelatinization temperature of its starch.

Water Uptake and Sedimentation (at 77° C. and 82° C.)

To 2 grams (±0.01) of milled rice in a 25- by 100-mm. test tube was added a measured amount of water. The volume of water was 6 to 8 ml. more than the amount absorbed by a 2-gram sample of that rice in a preliminary trial. The tube and contents were allowed to stand for 30 minutes, stoppered lightly to minimize evaporation losses, then immersed for 45 minutes in a water bath at the desired temperature (77° C. or 82° C.). At the end of this time, the tubes were immersed in cold water immediately to stop cooking action. Results with two samples (contrasting) are shown in figure 7. The contents were filtered through a Gooch crucible (size 3) with light suction into a graduated centrifuge tube. The filtrate was centrifuged at 1,800 r.p.m. (head radius, 8.5 inches) for exactly 5 minutes. Volume of sediment (representing insoluble solids) and the volume of unabsorbed water were then read (fig. 8). Absorbed water was determined by subtracting the unabsorbed from the original volume of water used in the test. Values for water uptake and sedimentation

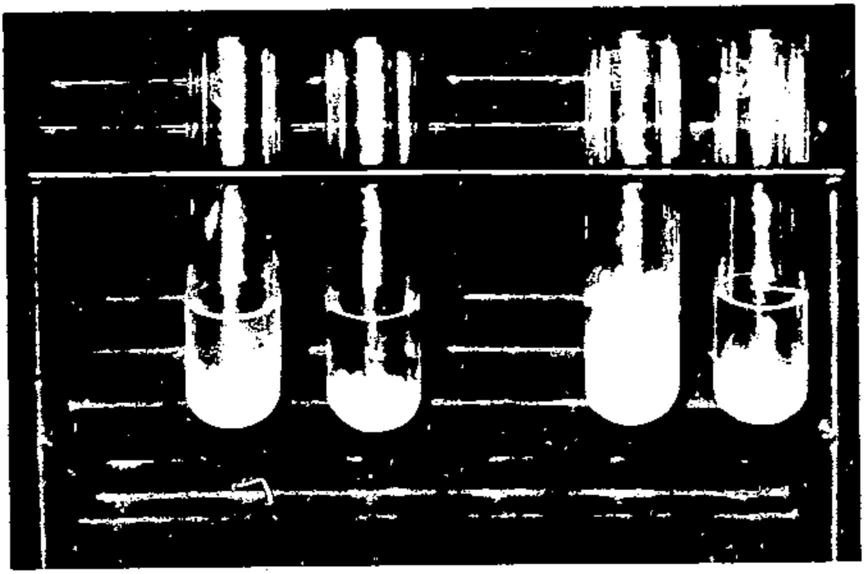

FIGURE 7.—Two U.S. varieties of rice before cooking (left pair) and after cooking (right pair).

value were obtained by calculating these data on the basis of 100 grams of rice *(16)*.

Alkali Spreading and Clearing

A liter of stock alkali solution, approximately 50 percent (weight per volume) in strength, was prepared by dissolving 588.2 grams of potassium hydroxide pellets (85 percent purity) in recently boiled and cooled distilled water. Sufficient distilled water was added to 33 ml. of the stock solution to make a liter of testing solution 1.7 percent (± 0.05) in strength. Final concentrations of the solutions were checked by titration. The solutions were protected from atmospheric carbon dioxide by drying tubes containing soda lime.

Six kernels of each rice lot were spaced evenly in a small transparent plastic box, size 1⅞ by 1⅞ by ¾ inch, resting on a black surface and containing 10 ml. of the test solution. The box was covered and left undisturbed 23 hours in a room maintained at about 70° F. Three replications of the treatment were made on each lot of rice. Samples were rated for spreading and clearing according to the 7-point scale *(31)*. Typical spreading and clearing values for the 7-point scale are illustrated in figure 9.

Kernels of Century Patna 231, which swell slightly but do not develop a collar, were used a a reference material; the spreading and clearing for this variety are each rated as "1."

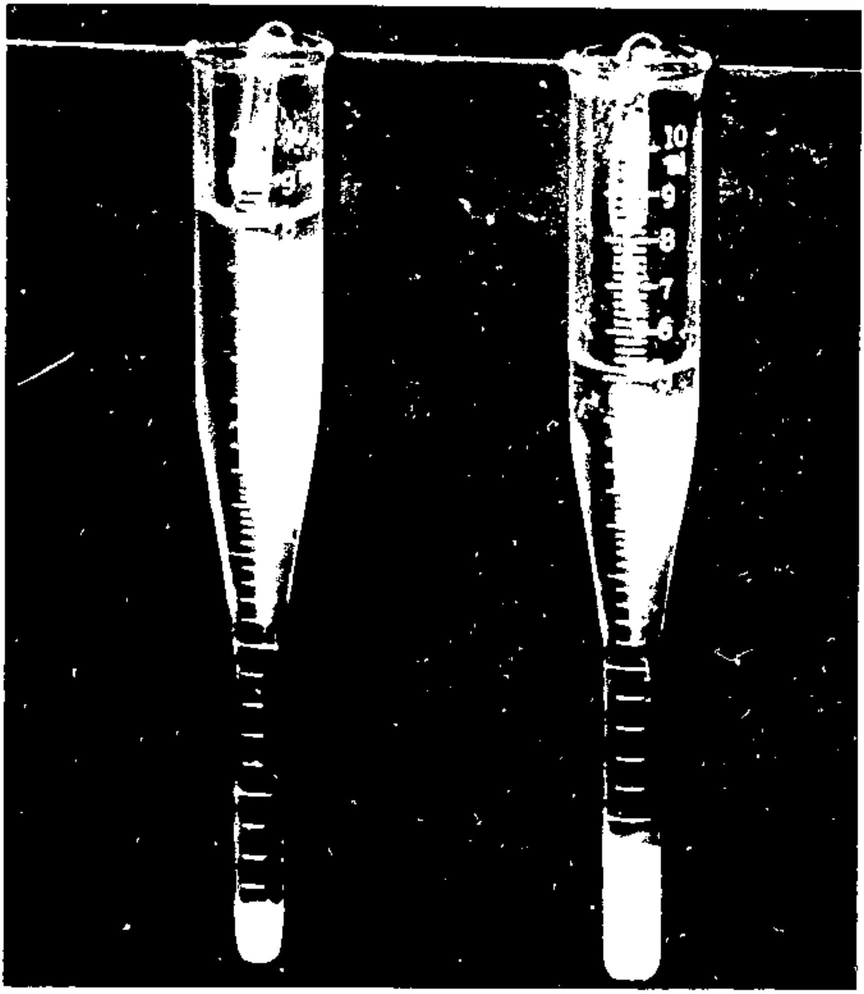

FIGURE 8.—Differences in amount of unabsorbed water and sediment (after centrifuging) in the two U.S. varieties shown in figure 7.

The condition of each kernel of rice was scored for *spreading* and *clearing* on 7-point scales (fig. 9) as follows:

Scale	Spreading	Clearing
1	Kernel not affected.	Kernel chalky.
2	Kernel swollen.	Kernel chalky; collar powdery.
3	Kernel swollen; collar incomplete or narrow.	Kernel chalky; collar cottony or cloudy.
4	Kernel swollen; collar complete and wide.	Center cottony; collar cloudy.
5	Kernel split or segmented, collar complete and wide.	Center cottony; collar clearing.
6	Kernel dispersed, merging with collar.	Center cloudy; collar cleared.
7	Kernels completely dispersed and intermingled.	Center and collar cleared.

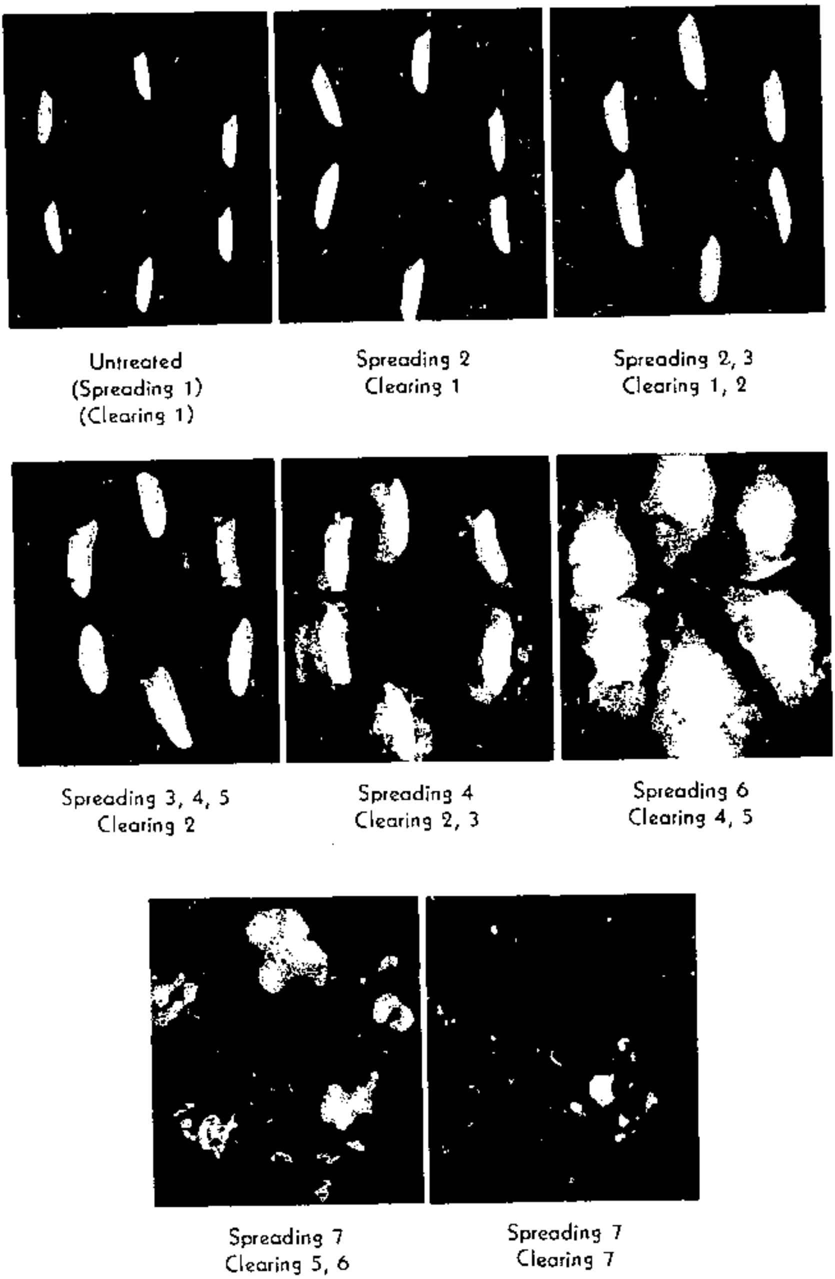

Figure 9.—Rice kernels of eight varieties treated with dilute alkali, illustrating spreading and clearing values 1 to 7.

Chemical Determinations

Lipid Content

Surface Lipids

Approximately 20 grams of a well-mixed sample of whole-milled rice was weighed into a 125-ml. flat-bottom boiling flask, refluxed with 25 ml. of petroleum ether, boiling range 35° to 38° C. for 25 minutes (fig. 10). The solvent was decanted through a folded filter (Whatman No. 12, 12.5 centimeters), in a 60° funnel, into a tared 100-ml. flat-bottomed extraction flask. The tared flask had been previously heated in a forced-draft oven at 101° to 104° C. for 30 minutes, cooled in a desiccator, and weighed.

FIGURE 10. Apparatus used in determining surface lipids of rice.

Fifteen milliliters of petroleum ether was added to the flask containing the rice, heated to boiling on a water bath, and decanted immediately through the filter previously used. This washing was repeated, except that the rice and solvent were completely transferred to the filter.

The filtered solvent was evaporated on a steam bath until the solvent odor had disappeared. The flask was removed from the steam bath, dried at 101° to 104° C. for approximately 30 minutes, cooled in a desiccator, and weighed. Residue was calculated as percentage of rice on a moisture-free basis and reported as surface lipids (*3, 19*).

Total Lipids

An accurately weighed 2-gram sample, ground to pass a 20-mesh sieve, was wrapped in a Whatman No. 43, 11-cm. filter paper, and rewrapped in a second paper of the same kind and secured with bright soft iron wire. The sample was placed one-fourth inch below the apex of the siphon of a Soxhlet extractor equipped with an Allihn condenser (Corning No. 3840—small) and extracted 16 hours with dry diethyl ether (fig. 11). Siphoning intervals were 5 minutes or less. The extraction flask, which had been previously tared, was removed from extraction setup and the ether was allowed to evaporate in a fume cupboard. Extracted lipid material was dried for 1 hour at 105° C., cooled, and weighed. The amount of lipids was calculated as percentage of rice on a moisture-free basis (*2, p. 371*).

Protein (Nitrogen)

About 2 grams of a sample (previously ground to pass a 20-mesh sieve) was weighed accurately and transferred to a Kjeldahl flask. A scoop (16 ±0.1 gram) of the mixed catalyst (1,500 grams of potassium sulfate and 70 grams of mercuric oxide blended in a ball mill or other suitable mixers) was added and washed down the neck of the flask with 25 ml. of 98 percent sulfuric acid. The mixture was digested until the solution cleared, and heating was continued for 2 hours (oxidation is probably completed 30 minutes after clearing). After completion of the digestion, the flask was cooled and 300 ml. of water added. After the flask was cooled again, 50 ml. of the sodium hydroxide-sodium thiosulfate solution (450 grams of sodium hydroxide dissolved in water, cooled, 80 grams of sodium thiosulfate added, and the volume diluted to 1 liter) was poured carefully down the neck of the flask, and a few pieces of zinc were added. The flask was attached to the distillation equipment and swirled to mix contents. The mixture was distilled into an Erlenmeyer flask containing 50 ml. of 5 percent boric acid solution (held below 40° C. during the entire distillation period) until about 250 ml. of distillate had been received. Titration was done with standard sulfuric acid, using Universal Indicator (*2, p. 368* and *secs. 2.21* and *2.23 modified*). Nitrogen determined in this way was calculated as percentage of rice on a moisture-free basis. Percentage of protein was computed by multiplying the nitrogen content by the factor 5.95. (The Kjeldahl digestion and distillation equipment is shown in fig. 12.)

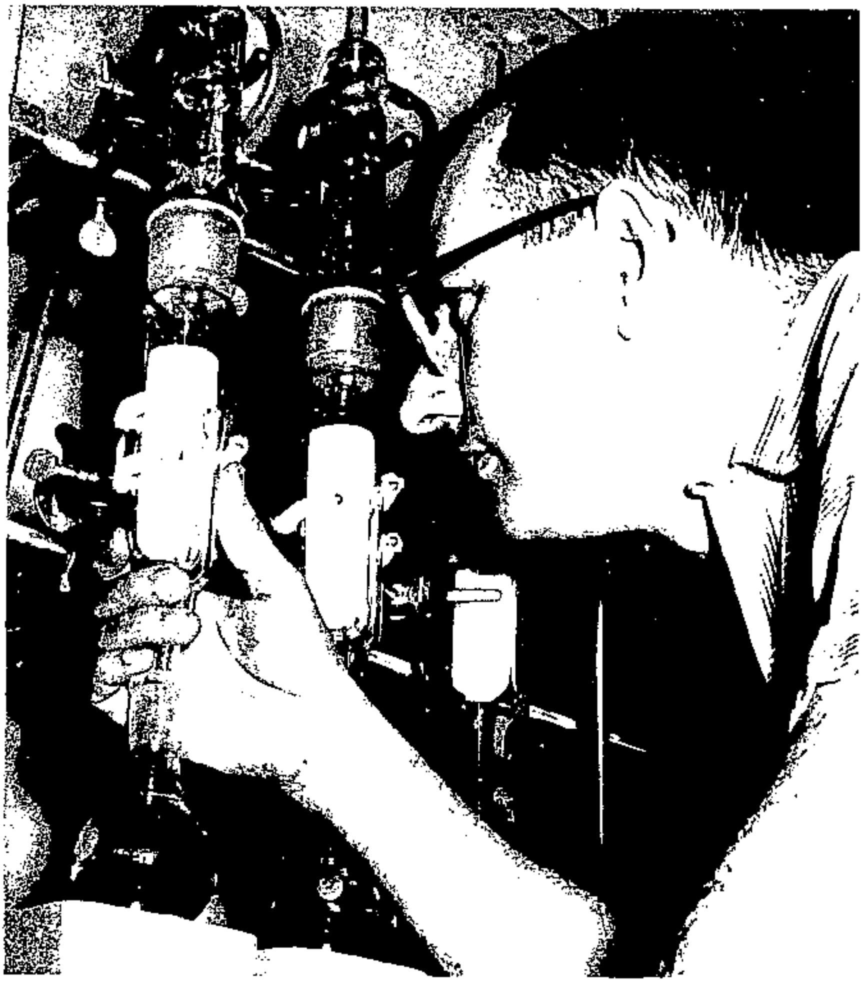

FIGURE 11.—Determining total lipid of rice by Soxhlet extraction method.

Moisture

Two grams of a well-mixed sample, previously ground to pass a 20-mesh screen, was weighed into a tared covered aluminum dish. With the cover loosened, the sample was heated in a vacuum oven at 100° ± 0.5° C., for 5 hours at 3-mm. pressure or less. The oven was brought to atmospheric pressure with dry air, and the cover was tightened on the dish. The dish was then transferred to the desiccator (fig. 13), cooled to room temperature, and weighed soon afterward. Loss of weight was calculated as percentage of moisture in the rice (*2, p. 206*) (wet basis).

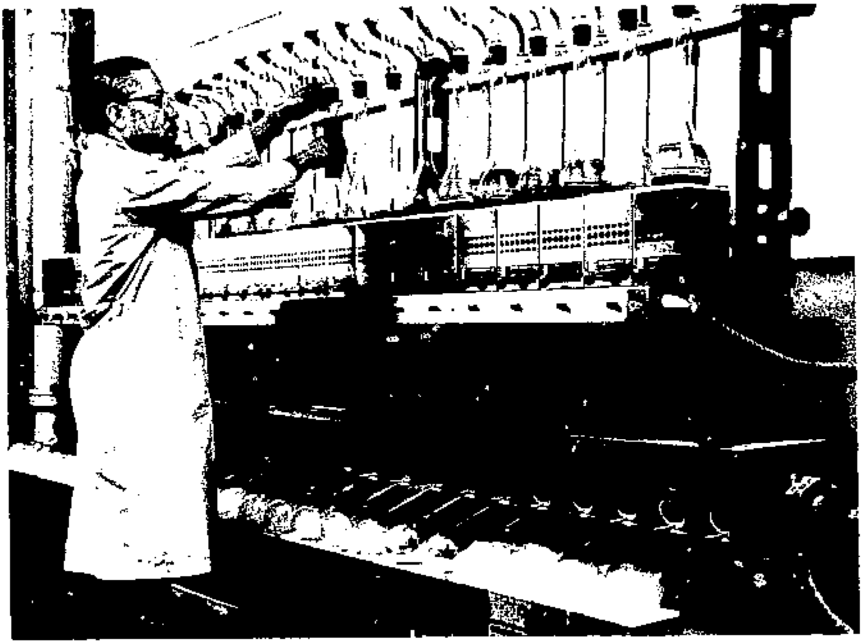

FIGURE 12.—Kjeldahl digestion and distillation equipment for nitrogen analysis in the protein determination of rice.

Crude Fiber

The ether-extractable material in polished rice samples tested was usually less than 0.5 percent, so the crude fiber determination was made without ether extraction.

A 2-gram sample, previously ground to pass a 20-mesh sieve, was placed in a 600-ml. beaker with about 0.5 gram of asbestos and 2 to 3 drops of antifoam agent (1 part methyl benzoate and 1 part tributyl citrate). Then 200 ml. of boiling sulfuric acid solution (0.255 *N*) was added and the digestion beaker immediately placed on a preheated hot plate and connected to a condenser. After the contents of the beaker reached the boiling point (in about 1 minute), they were boiled briskly for 30 minutes. (The beaker was rotated occasionally to assure mixing and to wash down material collecting on the sides of the beaker above the liquid level.) The solution was filtered with suction through linen cloth (about 45 threads per inch, such as that made by National Filter Media Corp.) on a Buchner funnel into a beaker. The beaker and filtered residue were washed with boiling water until the residue was no longer acid. Then the residue was transferred to another beaker with 200 ml. of hot alkali (0.313 *N* sodium hydroxide, free or nearly free of carbonate) until the 200-ml. mark on the beaker was reached. (The solution of sodium hydroxide was kept boiling under reflux. The setup was high enough that the alkali was delivered by siphon with sufficient force to facili-

FIGURE 13.—Apparatus for *in vacuo* determination of moisture content of rice.

tate the transfer of the residue to the beaker.) The beaker and contents were placed on the hotplate and connected to the condenser, brought to boil in 1 minute, and boiled 30 minutes longer. Then the digestion mixture was filtered with suction through a Gooch crucible on which an asbestos mat had been previously prepared, and washed thoroughly with boiling water. The filtration from the alkaline solution had to be completed in 5 minutes or less, to maintain a standard time of treatment. When free of alkali, the residue was washed with 15 ml. of 95 percent ethyl alcohol. Suction was continued, to remove alcohol in the mat and residue. After drying at 110° C. overnight, the crucible was cooled in a desiccator, and weighed. The crucible and contents were heated at 550° C. for

30 to 45 minutes, cooled in a desiccator, and again weighed. Loss in weight was calculated as percentage of rice on a moisture-free basis and recorded as percentage of crude fiber. (The apparatus for determining crude fiber is shown in fig. 14 (*2, p. 211* and *secs. 22.31*, *22.32*, and *22.33*).)

Ash

A 2-gram sample, previously ground to pass a 20-mesh sieve, was accurately weighed into a 30-ml. Vycor crucible and placed in a muffle furnace preheated to 600° C. (fig. 15). This temperature was maintained for 2 hours, after which the crucible was transferred to a desiccator, cooled, and weighed immediately. Weight of the residue was calculated as percentage of rice on a moisture-free basis and reported as percentage of ash (*2, p. 368*).

Starch Content

Total Starch

A 1.0- to 1.5-gram portion of the whole rice sample, ground to pass a 60-mesh standard screen, was weighed into a 50-ml. round-bottom centrifuge tube, and moistened with approximately 0.5 ml. of 80 percent ethanol. Then 5 ml. of water and 25 ml. of hot 80 percent ethanol were added and, with a rubber-tipped glass rod, were mixed with the sample. (The same rod was used for each sample throughout

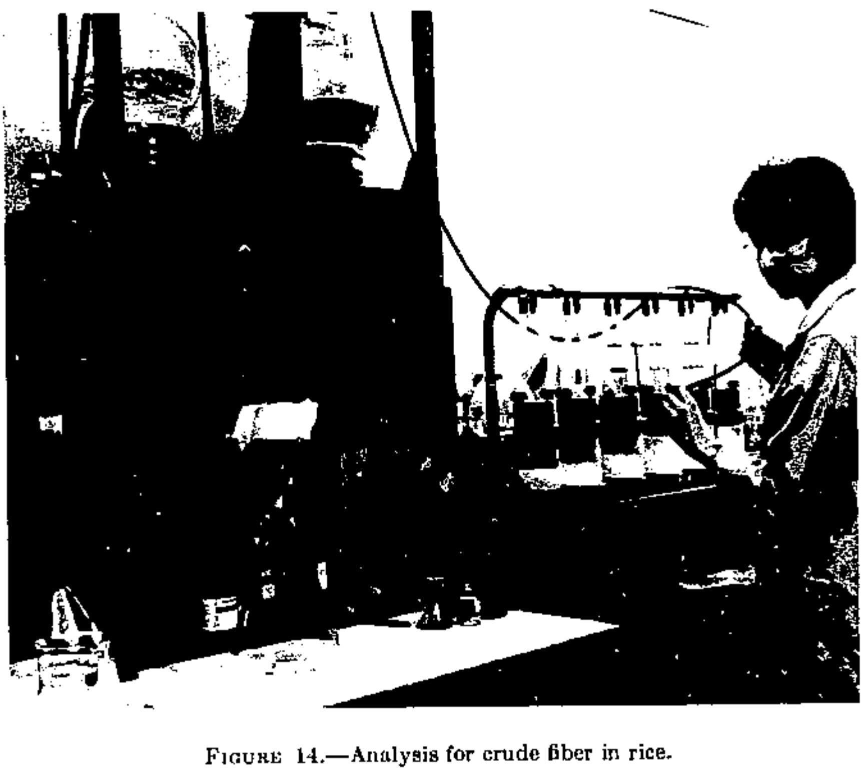

FIGURE 14.—Analysis for crude fiber in rice.

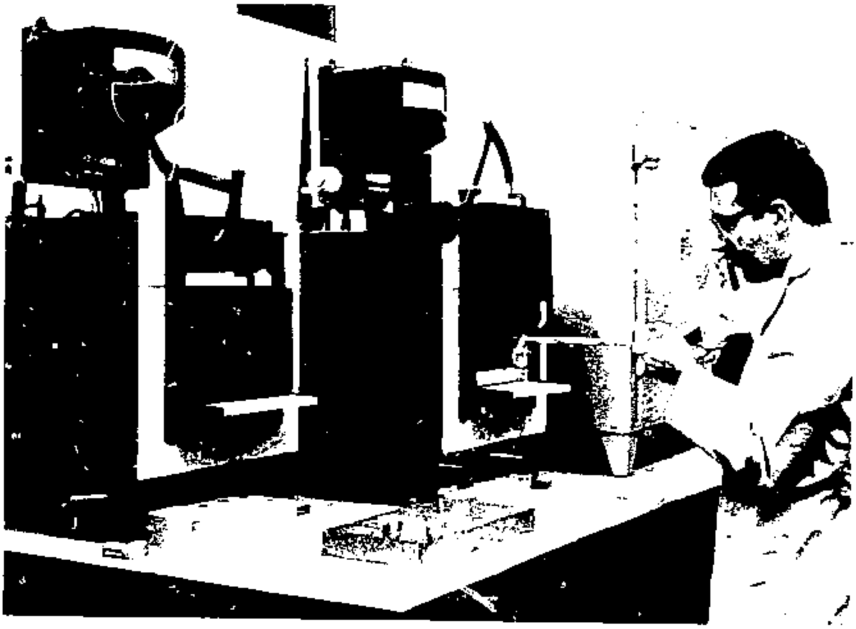

FIGURE 15.—Determining ash content of rice.

the washing and subsequent dispersion, to avoid loss or contamination of the sample. After standing for 10 minutes, the slurry was centrifuged at 2,000 r.p.m. (650 r.c.f.) for 10 minutes and the liquid layer decanted. The residue was treated with 30 ml. of hot 80 percent ethanol, stirred, let stand 10 minutes, centrifuged, and decanted.

The residue was then transferred to a 400-ml. Berzelius beaker, with two 5-ml. portions of water and then 60 ml. of calcium chloride-acetic acid solution (approximately 388 grams of anhydrous calcium chloride per liter plus glacial acetic acid to give pH 2.4). The liquid level was marked on the beaker. The mixture was brought to boiling in 5 minutes in a glycerin bath (one-half inch deep, 130° to 145° C.). The beaker was covered with a watch glass and boiled briskly for 15 minutes, with frequent stirring; water was added to keep the liquid level to the mark. When frothing became troublesome, a few drops of octanol or a small piece of cetyl alcohol was added.

The flask and contents were cooled in running water and treated with 10 ml. of uranyl acetate solution (made by dissolving 5 grams of uranyl acetate in 100 ml. of the calcium chloride-acetic acid solution). The mixture was then transferred to a 100-ml. volumetric flask and made up to volume with the calcium chloride-acetic acid solution. Foaming in the neck of the flask was controlled with a drop or two of 95 percent ethanol, and the mixture was shaken as the alcohol reached the froth. After thorough mixing, 40 to 50 ml. of the solution was transferred to a 50-ml. round-bottom centrifuge tube and centrifuged for 10 minutes (at 2,000 r.p.m., 650 r.c.f.). The liquid was decanted into a 2-decimeter polarimeter tube. (Cloudy dispersions after the last centrifuging step sometimes resulted if the solution was not boiled vigorously or if the sample was stored after grinding.) With sodium light used in the polarimeter, 10 rotation readings were taken (5 from the left and 5 from the right) and averaged (*9*). (See fig. 16.)

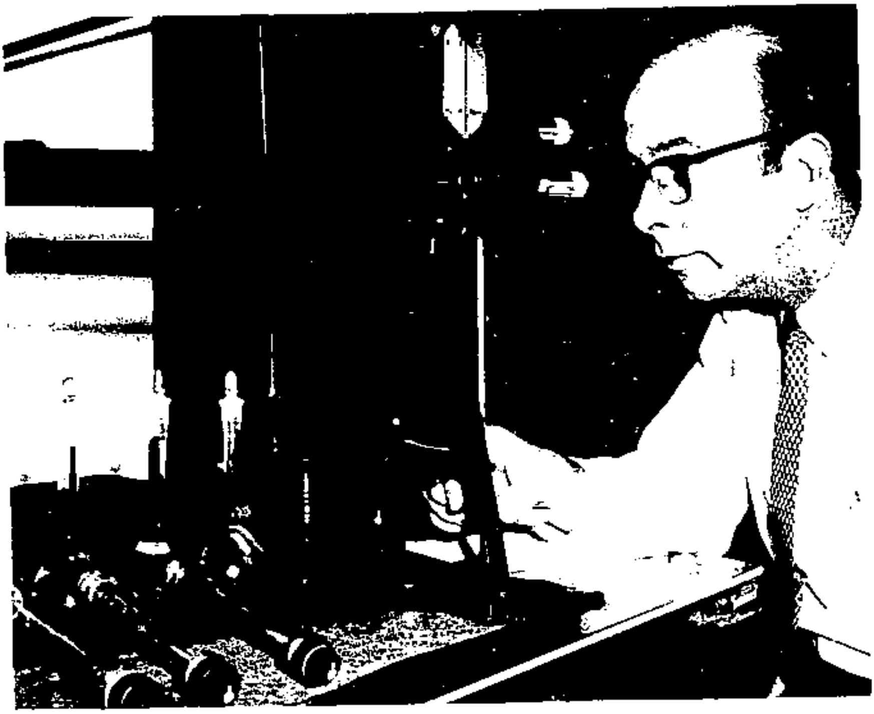

FIGURE 16.—Polarimetric determination of total starch content of rice.

Calculations:

$$\text{Percentage of starch (dry basis)} = 24.63 \times \frac{\text{A° (reading)}}{\text{weight of sample (dry basis)}}.$$

Amylose and Amylopectin

A 1-gram sample, ground to pass a 60-mesh standard screen, was accurately weighed into a round-bottom centrifuge tube, to which was added 20 ml. of absolute methanol. Mild shaking was used to disperse the sample. After standing 2.5 hours, the mixture was centrifuged 10 minutes at 2,000 r.p.m. (650 r.c.f.) and the upper layer decanted carefully.

Then 20 ml. of absolute methanol was added to the residue, with shaking, and after standing 16 to 18 hours at room temperature, the mixture was centrifuged as before.

The residual methanol was removed by immersing the tube in a warm water bath and blowing the sample with a fine stream of air.

The dried sample was quantitatively transferred into a Waring Blendor bowl with 5 ml. of 95 percent ethanol. Then 90 ml. of 1 *N* sodium hydroxide was added and blending was started immediately. (Delay causes caking, clumping, or adhesion of material under the rotor.)

The foam was broken with 5 ml. of ethanol, and the dispersion was transferred to a beaker. Then 10-ml. aliquots of the blended dispersion were pipetted into a 100-ml. volumetric flask, allowed to

FIGURE 17. Colorimetric determination of amylose starch in rice by reaction of iodine and amylose.

stand in a refrigerator at 0° to 4° C. for 1 hour, and diluted to volume with cold distilled water.

After an additional 18 hours in the refrigerator, a 5-ml. aliquot of this solution was pipetted into a 150-ml. beaker containing 50 ml. of distilled water. Hydrochloric acid (0.05 *N*) was added to an apparent pH reading of 10.5. Then 2 ml. of iodine solution (0.2 gram of iodine plus 2.0 grams of potassium iodide diluted to 100 ml.) was added, and the contents of the beaker were transferred to a 100-ml. volumetric flask and filled to the mark with distilled water.

Transmittance at 590 microns was read on a spectrophotometer 20 minutes after the iodine solution was added, and the percentage of amylose was determined by reference to a standard amylose curve established by using pure rice amylose isolated by the procedure of Wilson and Schoch (*46*) as the standard (figure 17).

Standard curve for amylose determination:

Pure amylose dispersed in alcoholic sodium hydroxide was transferred in 10-, 15-, 20-, 25-, 30-, and 35-mg. quantities to 150-ml. beakers containing 50 ml. of water. After the solutions were neutralized to pH 10.5, they were treated as described for the sample. Transmittances at 590 microns when plotted against amylose showed a linear relationship (*34*, *41*, *45*, *46*).

Percentage of amylopectin is determined by mathematical difference between the percentages of *total starch* and *amylose*.

Amylose/Amylopectin Ratio

The *amylose/amylopectin ratio* is a mathematical ratio calculated from the percentages of amylose and amylopectin determined for the particular rice sample.

Starch-Iodine-Blue Value

A 1.00-gram sample of milled rice, ground to pass through a 0.5-mm. screen, was transferred to a 250-ml. Erlenmeyer flask. Exactly 100 ml. of distilled water was added, and the flask and contents were immersed for 45 minutes in a water bath maintained at 77° C. The sample was removed from the bath, allowed to stand at room temperature for 15 minutes, and filtered through Whatman No. 12 filter paper. The first 30- to 40-ml. portion of the filtrate was discarded. A 10-ml. aliquot of the filtrate was pipetted into a 100-ml. volumetric flask containing 1 ml. of iodine solution (2 grams of iodine and 20 grams of potassium iodide in 1 liter of solution), 1 ml. of 30 percent hydrochloric acid, and approximately 60 to 70 ml. of distilled water. The flask, after being filled to the mark (fig. 18), was shaken and allowed to stand at room temperature for at least 30 minutes. The intensity of the blue color was determined in a photoelectric colorimeter at 600 microns and recorded as the iodine-blue value (*17*). (In the instrument, percentage of transmission was set at 100 with a solution of 1 ml. of iodide and 1 ml. of acid solution in 100 ml. of distilled water.)

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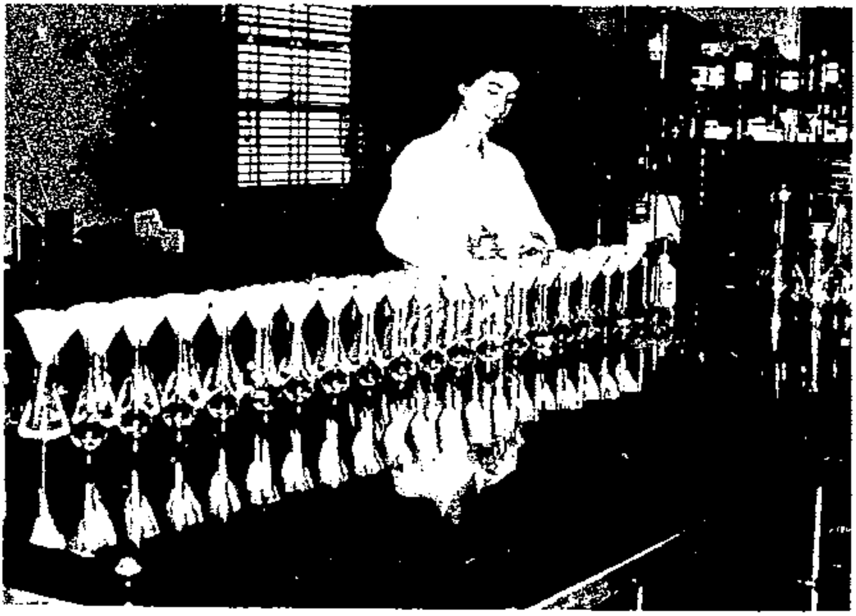

FIGURE 18.—Starch-iodine-blue test.

Palatability Characteristics (After Cooking) (Appearance, Cohesiveness, Tenderness, Flavor)

Cooking quality characteristics of appearance, cohesiveness, tenderness, and flavor were determined on selected samples of cooked rice. Selection of samples was based on the grading characteristics as well as on the results of preliminary physical and chemical tests of each lot. These cooking tests have been described (*5, 6*). Typical changes in appearance of rice kernels on cooking are shown in figure 19.

To obtain a more direct comparison of the cooking quality of the foreign rices with each other and with U.S. rices, all samples were cooked by a standard oven method (*5, 6*).

One hundred grams of rice (without prior washing) was added to a predetermined volume of boiling water in a covered 1-quart Pyrex baking dish and cooked in a 350° F. oven for 28 minutes (33 minutes for parboiled samples). The lid was then removed and the rice was allowed to steam in the oven 5 minutes longer.

For each lot of rice, the volume of water used in cooking the rice was calculated from the amount of water absorbed when an 8-gram sample of rice was cooked in 160 ml. of boiling water for 20 minutes.

For the panel taste tests (figs. 20, 21), five trained panel members were served four samples of cooked rice, one at a time, on warmed white plates at 4-minute intervals. The rice was served immediately

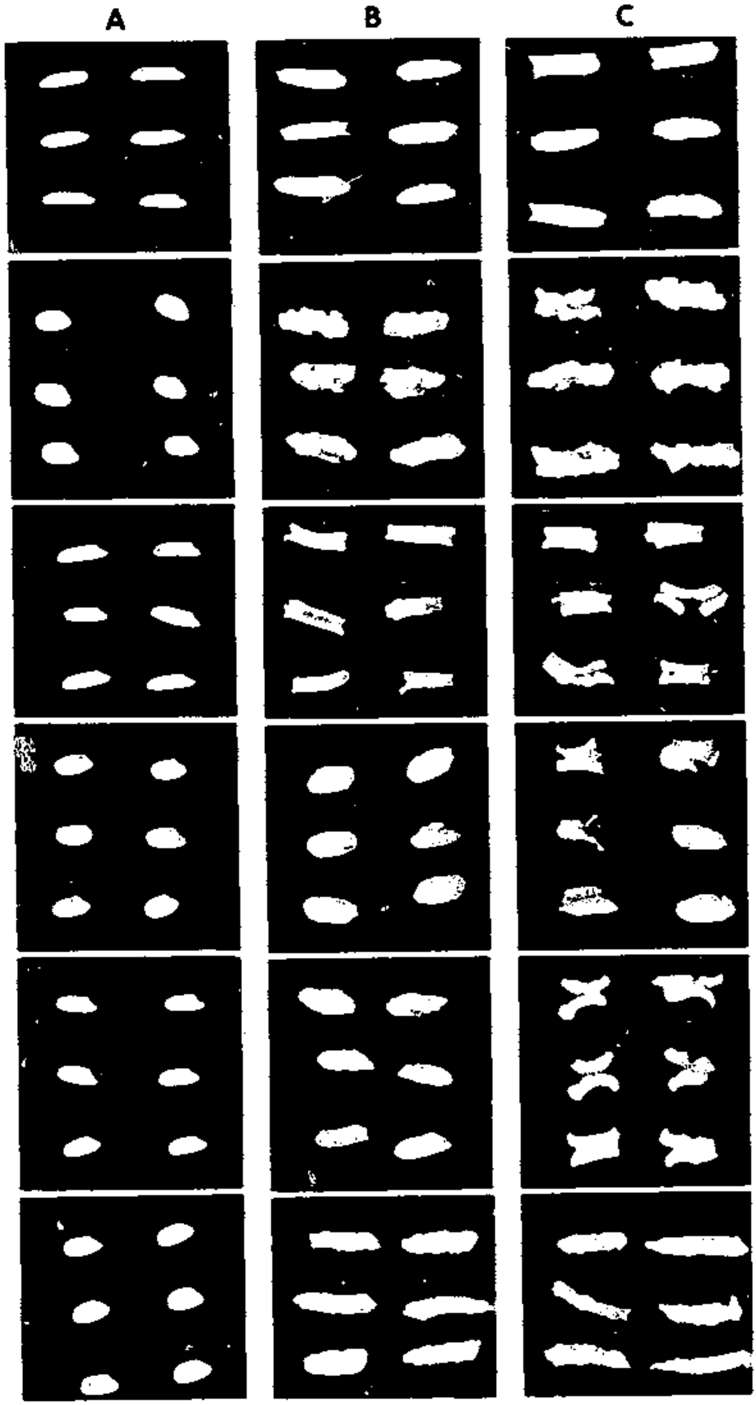

FIGURE 19.—Changes in appearance of rice kernels on cooking. (A) Raw. (B) Cooked 28 minutes. (C) Cooked, followed by 18 hours' soaking.

FIGURE 20.—Room used by panel members for palatability evaluations of foods.

FIGURE 21.—One panel member scoring the palatability characteristics of cooked rice.

after cooking. The panel members rated the samples for appearance, cohesiveness, tenderness, and flavor, on 9-point scales:

Scale	Appearance	Cohesiveness	Tenderness	Flavor
9	Whole smooth grains.	Well-separated grains.	Hard centers.	No off-flavor; bland.
7	Fuzzy edges.	Partially separated.	Firm and chewy.	Perceptible off-flavor.
5	Sloughing.	Sticky or slightly clumped.	Tender and firm.	Slightly strong off-flavor.
3	Indistinct broken grains.	Very sticky, clumped.	Soft.	Moderately strong off-flavor.
1	Disintegrated.	Pasty.	Mushy.	Very strong off-flavor.

Since the production, processing, handling, and storage conditions of the rice varied greatly between the time the rice was planted and when it was selected at the market, the mild natural flavor of the rice was frequently overshadowed by other flavors, such as rancidity and mustiness. In some cases, these other flavors would be characteristic of the rice of the country from which the sample was obtained. However, the flavor would not be characteristic of rice in the United States and was, therefore, considered to have an off-flavor in this investigation. No attempt was made to measure preference for different kinds of rice. The trained panel rated only the degree of a certain quality characteristic present in a rice sample.

Additional information on cooking quality was obtained for many of the samples by using the cooking methods commonly used in the countries of origin. The special cooking processes used and a discussion of the findings have been published separately by the Human Nutrition Research Division of the Agricultural Research Service.[7]

[7] BATCHER, O. M., STALEY, M. G., and DEARY, P. A. PALATABILITY CHARACTERISTICS OF FOREIGN AND DOMESTIC RICES COOKED BY DIFFERENT METHODS. Rice Jour. 66 (9): 19–24 (Aug. 1963) and 66 (10): 13–16 (Sept. 1963).

PART III.—EVALUATION OF RICE QUALITY MEASUREMENTS

How Data Were Studied

The analytical data obtained in these studies of the 26 quality characteristics of rice samples from 33 foreign countries and the United States have been extensively examined. Data are presented for long-, medium-, and short-grain rices under the categories of "milled rice" and "parboiled milled rice." Since only six glutinous rice samples and one parboiled short-grain rice sample were received, these two categories have been omitted from this report. Emphasis has been placed on the milled-rice studies, since the milled rices outnumbered the parboiled milled rices by more than 7 to 1 in this study, and since parboiling introduces another unknown variable affecting quality.

The analytical determinations were made by the four ARS laboratories whose findings are reported herein, and by the AMS Grain Laboratory (New Orleans) at the request of FAS and used in its publication, "Analysis of Selected Varieties and Grades of Rice Moving in World Trade," referred to in part I (*39*).

Findings that appear particularly significant are pointed out in the discussion of each of the 26 quality factors. Each quality factor discussion is accompanied by a summary table that shows, for each *country:* (a) The actual number of samples examined under each test, since the number varied considerably because of the sampling pattern and limitation of resources available for the laboratory determinations; (b) the mean values; and (c) the range of values for the analytical results pertaining to each quality factor (tables 1–26).

In addition, each table gives summarizing information for "all samples" of long-, medium-, and short-grain rices, regardless of country where obtained, for the same categories given for the individual countries.

For each quality characteristic, statistical studies have been made for the milled rice samples to determine *what correlations may exist between that particular quality characteristic and each of the other quality factors* (except moisture, crude fiber, and ash [5]). For example, calculations were made to determine what correlations existed between total lipids and each of the other 22 quality characteristics. In the same manner, each quality factor was compared with each of the other 22 quality factors. An attempt has been made to interpret any such correlations in terms of scientific knowledge, and to differentiate from what may be mere mathematical coincidences.

[5] Unknown storage and handling background made moisture determination meaningless; ranges of crude fiber and ash content were too narrow for correlation purposes.

The number of samples available did not permit, in most cases, statistical calculations according to individual countries. However, for the raw milled rices, correlation studies were made on "all samples" (*combined* long-, medium-, and short-grain types) and on all long-, all medium-, and all short-grain types, irrespective of individual countries. Table 27 shows the significant correlation values found in these studies.

For the benefit of the reader not familiar with statistical correlation studies, a correlation coefficient of 1.000 implies perfect correlation, whether it be positive or negative in sign. A positive sign indicates that as the measurements for one property increase or decrease, those of the other property follow in the same direction. A negative sign indicates that the direction of trend of one measurement is the reverse of that of the other. The more the figure decreases from 1.000, the lower is the degree of correlation, until below a certain point no significance is indicated. This is not a fixed point for all calculations—it is lower, for example, the greater the number of data available for a given calculation.

Examination of the data in table 27 reveals that the relation between two factors is affected more or less by a third variable and possibly others. To what extent this is true is determined by the value of the coefficient, because the square of this figure indicates the percentage of variability of one factor accounted for by the second. For this to be greater than 50 percent, the correlation coefficient must exceed 0.707, whose square is 0.500. One must also bear in mind that correlation coefficients, even though numerically "significant," may be spurious. Typical examples would be certain correlations involving percentage of broken kernels in commercial samples. Because broken kernels are often added to or partially removed from milled rice to meet grade requirements, there can be no true correlation of their percentage with, for example, composition factors. On the other hand, a subjective appearance score would be expected to correlate significantly with percentage of broken kernels, which was indeed the case in this investigation.

Physical Measurements

Kernel Length

Kernel length has long been used in most rice-growing areas as a characteristic for classifying rice varieties. Kernel width and thickness have also been used to further differentiate classes of rice (*7, 13, 18*). Graham (*13*) divides rice of India into long spikelet, fine, coarse, and round. Rice varieties in the United States generally are referred to as long-, medium-, and short- (pearl) grain. The U.S. long-grain varieties are in Graham's long spikelet or fine class, the medium-grain in the coarse class, and the short-grain in the round class.

In this study the samples were arbitrarily classified as to kernel length as follows:

Long-grain—6.16 mm. and longer.
Medium-grain—5.16 mm. to 6.15 mm.
Short-grain—5.15 mm. and shorter.

Certain cooking and processing characteristics are generally associated with a particular grain type in the relatively small number of varieties commonly grown in the United States. For example, most long-grain varieties have an intermediate gelatinization temperature and a relatively high amylose content, and are flaky when cooked. However, there are exceptions such as the long-grain Toro variety, which has a low gelatinization temperature, a relatively low amylose content, and is moist and somewhat cohesive when cooked (*15*). Thus, it is seen that kernel length and shape are not reliable indicators of cooking and processing characteristics. Even though chemical and physical characteristics cut across grain-type divisions, this system of classification is useful in discussing the usual qualities of rice, and affords a basis for comparing foreign rices among themselves as well as with U.S. rices.

Table 1 shows data on kernel length for samples from each country as well as for "all samples."

Milled Rice

On an "all samples" basis, there was no conclusive evidence that kernel length was significantly correlated with any of the 25 factors investigated. There were indications, however, suggesting a positive correlation between kernel length and cooking-quality cohesiveness, especially in the medium-grain rices; and between length and heat alteration, particularly in short-grain rices. These studies indicated that some characteristics may be associated with length, and need further study. From the standpoint of relating grain length with the other 25 quality factors, the medium-grain rices, as defined in this study, seem to have characteristics much different from those of either the long- or the short-grain rices. These differences were sufficient, in most cases, to reverse the sign of the correlation factors for the "all samples" from that of the long- and short-grain samples.

Long-grain.—The "all samples" long-grain rices averaged 6.80 mm., or 0.64 mm. above the minimum for this class. U.S. long-grain rices, averaging 6.76 mm., were about identical with the "all samples" average. Rices from Iran, averaging 7.44 mm., were the longest of all rices studied; those from Brazil, Colombia, and Greece, all exceeding 7.00 mm., were the next longest. The largest variation was found in the Thailand samples, whereas those from South Africa and Guatemala varied the least.

Medium-grain.—The average length of all the medium-grain foreign rices, as well as the U.S. samples, was very close to the median of this class (5.60 mm.). Variation was least for the Burma samples and greatest for those from the Phillippines. The 150 medium-grain samples averaged 0.06 mm. above the median for this class, according to U.S. grade standards.

Short-grain.—The short-grain samples averaged fairly close to the maximum for this class, with the U.S. rices averaging still closer to the maximum of 5.15 mm. The shortest specimen came from Ceylon, whose samples also had the widest range. The samples from Japan averaged about the same as the entire group.

Parboiled Milled Rice

Among the long-grain parboiled milled-rice samples, those from the United States were longest and those from Ghana the shortest of this group; those from Thailand had the greatest variation. The medium-grain rices from Thailand had the least range in length.

Kernel Width[9]

Kernel width alone is a little-recognized characteristic insofar as rice specifications are concerned, but is an important factor in determining the shape (length/width ratio) and weight of the kernel. Within U.S. rice varieties, those with wide kernels usually have lower gelatinization temperatures than those with narrower kernels (*16*). Kernel width also is associated with total milling yield and with consumer preference (*14*).

Detailed data concerning kernel width are given in table 2.

Milled Rice

A negative correlation seems indicated between kernel width and broken kernels, especially in the shorter grain types (table 27). It is noteworthy, however, that these studies did not reveal any relation between kernel width and any of the other 24 quality factors.

Long-grain.—The U.S. samples (2.02 mm.) were in the group of least width, with only those from India, Iran, and West Pakistan having slightly less width. The samples from Italy had the greatest width.

Medium-grain.—Samples from Greece and Turkey averaged the widest; from India and West Pakistan, the narrowest. Samples from 9 countries averaged narrower and 10 wider than the mean of U.S. samples (2.55 mm.). Variation was extremely low for all countries except India and Peru.

Short-grain.—These samples had greater width than either the long- or medium-grain samples. Seven had greater width than those from the United States. India samples had the least width of any and had by far the greatest range.

Parboiled Milled Rice

All long-grain samples were relatively narrow and were in a rather close range. The medium-grain rices averaged greater width than the long-grain samples.

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[9] Kernel width is sometimes referred to as "kernel breadth."

TABLE 1.—KERNEL LENGTH: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Mm.	*Mm.*		*Mm.*	*Mm.*		*Mm.*	*Mm.*
"All samples"	168	6.80	6.16–7.70	150	5.60	5.16–6.14	129	4.90	3.84–5.15
U.S.A.	6	6.76	6.50–7.08	5	5.68	5.37–6.06	2	4.96	4.92–5.01
Africa, South	2	6.46	6.45–6.46	1	5.39		2	4.72	4.69–4.75
Argentina	2	6.21	6.17–6.25	5	5.64	5.50–5.98	4	4.96	4.85–4.94
Australia							1	5.06	
Brazil	7	7.01	6.40–7.30	5	5.86	5.47–6.08	3	4.99	4.97–5.02
Burma	11	6.62	6.48–6.86	35	5.47	5.21–5.87			
Ceylon				7	5.42	5.16–5.63	3	4.56	3.84–5.04
Chile									
Colombia	4	7.11	6.78–7.67	1	6.13				
Ecuador	2	6.82	6.47–7.17	4	5.76	5.57–5.93			
Egypt							5	4.93	4.81–5.10
El Salvador	2	6.89	6.76–7.02						
France	4	6.92	6.78–7.08				2	4.74	4.74–4.75
Germany, West	5	6.72	6.62–6.87	4	5.71	5.45–5.94	3	4.92	4.85–5.00
Ghana									
Greece	6	7.03	6.82–7.16	2	5.20	5.16–5.23	8	5.08	4.99–5.15
Guatemala	2	6.39	6.38–6.40						
India	20	6.67	6.16–7.03	21	5.66	5.26–6.07	8	4.65	4.00–5.05
Indonesia	18	6.78	6.42–7.07	8	5.62	5.19–6.14	4	4.98	4.93–5.11

Iran	9	7. 44	7. 04–7. 70	5	5. 53	5. 17–5. 83	1	5. 10	—
Italy	6	6. 94	6. 88–7. 03	—	—	—	3	5. 04	5. 04–5. 05
Ivory Coast	1	6. 96	—	—	—	—	1	5. 10	—
Japan	6	6. 69	6. 45–7. 00	18	5. 52	5. 20–6. 08	60	4. 91	4. 55–5. 15
Korea	—	—	—	—	—	—	10	4. 87	4. 73–4. 96
Mexico	9	6. 99	6. 71–7. 35	—	—	—	—	—	—
Nigeria	—	—	—	—	—	—	—	—	—
Pakistan, East	—	—	—	—	—	—	—	—	—
Pakistan, West	11	6. 69	6. 32–6. 98	1	6. 12	—	—	—	—
Peru	6	6. 64	6. 50–6. 76	4	5. 75	5. 69–5. 81	—	—	—
Philippines	—	—	—	11	5. 72	5. 18–6. 14	—	—	—
Portugal	1	6. 72	—	3	5. 52	5. 42–5. 69	1	4. 76	—
Spain	—	—	—	—	—	—	5	4. 80	4. 76–4. 86
Thailand	27	6. 71	6. 19–7. 51	7	5. 86	5. 59–6. 12	—	—	—
Turkey	1	6. 99	—	3	5. 46	5. 32–5. 56	3	4. 94	4. 87–5. 01

Continued

TABLE 1.—KERNEL LENGTH: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Mm.	*Mm.*		*Mm.*	*Mm.*
"All samples"	38	6. 59	6. 17–7. 34	26	5. 69	5. 03–6. 13
U.S.A.	1	7. 33				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	6. 27	6. 17–6. 47	8	5. 68	5. 22–6. 13
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	5. 52	5. 03–6. 00
Ghana	1	6. 21				
Greece						
Guatemala						
India	6	6. 68	6. 20–7. 03	7	5. 65	5. 33–5. 93
Indonesia						

Iran	---	---	---	---	---	---
Italy	---	---	---	---	---	---
Ivory Coast	---	---	---	---	---	---
Japan	---	---	---	---	---	---
Korea	---	---	---	---	---	---
Mexico	---	---	---	---	---	---
Nigeria	1	6. 73	---	---	---	---
Pakistan, East	6	6. 36	6. 23–6. 54	6	5. 74	5. 37–6. 12
Pakistan, West	6	6. 55	6. 21–6. 83	---	---	---
Peru	---	---	---	---	---	---
Philippines	---	---	---	---	---	---
Portugal	---	---	---	---	---	---
Spain	---	---	---	---	---	---
Thailand	14	6. 70	6. 21–7. 34	3	5. 76	5. 54–5. 96
Turkey	---	---	---	---	---	---

TABLE 2.—KERNEL WIDTH: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Mm.	*Mm.*		*Mm.*	*Mm.*		*Mm.*	*Mm.*
"All samples"	168	2. 28	1. 73–3. 35	150	2. 52	1. 65–3. 05	128	2. 80	1. 65–3. 06
U.S.A.	6	2. 02	1. 92–2. 10	5	2. 55	2. 49–2. 66	2	2. 90	2. 82–2. 97
Africa, South	2	2. 16	2. 10–2. 21	1	2. 52		2	2. 66	2. 65–2. 68
Argentina	2	2. 83	2. 82–2. 84	5	2. 64	2. 55–2. 77	4	2. 92	2. 85–2. 99
Australia							1	3. 06	
Brazil	7	2. 48	2. 07–2. 69	5	2. 69	2. 59–2. 81	3	3. 04	3. 03–3. 06
Burma	11	2. 39	2. 13–2. 48	35	2. 53	2. 34–2. 92			
Ceylon				7	2. 52	2. 40–2. 72	3	2. 44	2. 40–2. 46
Chile									
Colombia	4	2. 45	2. 07–2. 60	1	2. 71				
Ecuador	2	2. 16	2. 08–2. 23	4	2. 30	2. 15–2. 44			
Egypt							5	2. 77	2. 72–2. 81
El Salvador	2	2. 24	2. 19–2. 30						
France	4	2. 71	2. 51–2. 82				2	2. 80	2. 77–2. 84
Germany, West	5	2. 24	2. 05–2. 88	4	2. 71	2. 54–2. 78	3	2. 91	2. 82–3. 01
Ghana									
Greece	6	2. 77	2. 71–2. 86	2	3. 00	2. 99–3. 00	8	2. 94	2. 85–2. 97
Guatemala	2	2. 32	2. 23–2. 40						
India	20	1. 98	1. 76–2. 28	21	2. 16	1. 65–2. 50	8	2. 10	1. 65–2. 69

Indonesia	18	2. 38	2. 11–2. 70	8	2. 49	2. 22–2. 75	4	2. 90	2. 87–2. 92
Iran	9	1. 92	1. 81–2. 00	5	2. 81	2. 63–3. 05	1	3. 10	----------
Italy	6	3. 09	2. 83–3. 35	------	------	----------	3	3. 01	3. 00–3. 02
Ivory Coast	1	2. 11	----------	------	------	----------	1	2. 74	----------
Japan	6	2. 21	2. 14–2. 32	18	2. 77	2. 41–3. 01	60	2. 83	2. 67–2. 99
Korea	------	------	----------	------	------	----------	10	2. 84	2. 75–2. 96
Mexico	9	2. 21	2. 01–2. 42	------	------	----------	------	------	----------
Nigeria	------	------	----------	------	------	----------	------	------	----------
Pakistan, East	------	------	----------	------	------	----------	------	------	----------
Pakistan, West	11	1. 96	1. 73–2. 22	1	2. 14	----------	------	------	----------
Peru	6	2. 52	2. 48–2. 56	4	2. 58	2. 17–3. 00	------	------	----------
Philippines	------	------	----------	11	2. 31	2. 06–2. 48	------	------	----------
Portugal	1	2. 68	----------	3	2. 82	2. 74–2. 88	------	------	----------
Spain	------	------	----------	------	------	----------	5	2. 87	2. 77–2. 95
Thailand	27	2. 21	1. 99–2. 58	7	2. 33	2. 17–2. 46	------	------	----------
Turkey	1	2. 88	----------	3	2. 90	2. 76–3. 01	3	2. 73	2. 46–2. 98

Continued

TABLE 2.—KERNEL WIDTH: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Mm.	*Mm.*		*Mm.*	*Mm.*
"All samples"	36	2. 13	1. 83–2. 45	26	2. 30	1. 66–2. 93
U.S.A.	1	2. 06				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	2. 18	2. 09–2. 22	8	2. 38	2. 26–2. 48
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	2. 90	2. 86–2. 93
Ghana	1	2. 22				
Greece						
Guatemala						
India	6	2. 08	1. 83–2. 45	7	2. 08	1. 66–2. 56

Indonesia	---	---	---	---	---	---
Iran	---	---	---	---	---	---
Italy	---	---	---	---	---	---
Ivory Coast	---	---	---	---	---	---
Japan	---	---	---	---	---	---
Korea	---	---	---	---	---	---
Mexico	---	---	---	---	---	---
Nigeria	1	2. 18	---	---	---	---
Pakistan, East	4	2. 04	1. 99–2. 09	6	2. 27	2. 10–2. 47
Pakistan, West	6	2. 09	2. 13–2. 21	---	---	---
Peru	---	---	---	---	---	---
Philippines	---	---	---	---	---	---
Portugal	---	---	---	---	---	---
Spain	---	---	---	---	---	---
Thailand	14	2. 17	1. 95–2. 31	3	2. 29	2. 25–2. 33
Turkey	---	---	---	---	---	---

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Broken Kernels

The data for "broken kernels" are governed primarily by method of grading, and may have no relationship to the milling quality of the rice. For this reason, data from these samples cannot be expected to correlate with U.S. rices or others in respect to 25 other quality factors in these studies (table 27).

Large percentages of broken kernels were found in the samples from about half of the 34 countries. Such samples could result from poor drying or milling practices, or from blending broken kernels with run-of-the-mill rice to meet certain grade designations and price differentials.

The wide range of percentage of broken kernels in the various categories should be noted. Percentage of broken kernels found in the samples in a particular country is perhaps a symbol of the rice quality standards to which that country is accustomed. Many of the countries apparently are tolerant to high counts of broken kernels.

Grain size (length and width) and degree of milling are not the entire cause of broken kernels in rice. Rice that is "chalky" (opaque centers) breaks more easily than vitreous rice. Changes in the rice kernels during drying also affect the proneness of rice kernels to break.

Milled Rice

As expected, there were negative correlations between broken kernels and cooking quality appearance (table 27).

Table 3 illustrates the results of the analytical work on the quality factor "broken kernels."

Long-grain.—The Indonesia samples had the highest percentages of broken rice, followed by those from Ivory Coast, El Salvador, Burma, Peru, Colombia, West Pakistan, and Guatemala. West Pakistan samples had, by far, the widest range, with those from Thailand, Brazil, and Burma high in this property. Smallest percentages of broken kernels were found in samples from Argentina, France, and Italy.

Medium-grain.—Indonesia again had the highest percentage of broken kernels. The medium-grain samples had the highest percentage of broken kernels of any types of rice.

Short-grain.—This type had the least amount of broken kernels. Japan, a major consumer of short-grain rice, had one of the very lowest percentages of broken kernels.

Parboiled Milled Rice

The samples from Ghana and Nigeria contained more than 40 percent broken kernels, and samples from Burma, East Pakistan, and West Pakistan all had high amounts of broken kernels. Thailand samples, however, had a surprisingly low content of broken kernels.

Kernel Color

Color is an important quality factor for rices all over the world. Customs vary from country to country—with premium placed by many on the whiteness of the milled rice. Whiteness has been associated with purity and has accounted for some of this preference.

It would be more accurate, however, to associate whiteness with the completeness of milling. Ironically, the greater the milling and whiter the rice, the less nutritive value remaining in the rice.

The lightness or "L" values for the milled samples examined in this investigation ranged from about 52 for the darkest to about 78 for the lightest, and for the parboiled samples from about 44 to about 66 (table 4). On the average, medium-grain milled rices were slightly lighter than either the long- or short-grain rices in this quality, but the reverse was true for the medium-grain parboiled samples. The low ranges for "L" in the parboiled rices are in keeping with the color transformation that usually accompanies parboiling.

Milled Rice

There seemed to be rather consistent negative correlations between "L" values (color lightness) and total lipids (table 27). The amount of both surface and total lipids is influenced by the degree of milling (*3*), and the degree of milling influences the whiteness of the rice. This negative correlation was found in long-, medium-, and short-grain types but was most pronounced in the short-grain types.

Positive correlations seem to exist between "L" values and water uptake and sediment values, particularly at 82° C.

A negative correlation was indicated in medium- and short-grain rices, between "L" color and iodine-blue values.

The "L" values for all milled-rice samples ranged between 51.8 and 79.6—a spread of about 50 percent. Similar average "L" values were noted for the long-, medium-, and short-grain rices from any one country. Within grain types, there was much overlapping in the "L" values among rice samples from different countries.

Throughout all lengths, the India samples were the lowest in light value, with the color of the three length categories averaging almost the same but having by far the greatest variations (table 4). The U.S. samples averaged about midway of all samples considered. It is interesting to note that the "L" value for Japan long-grain was almost identical with the U.S. long-grain, the Japan medium-grain samples were slightly higher in "L" value, but the Japan short-grain samples were definitely lower in "L" value than the U.S. samples.

In addition to variations in lightness values, it was noted that some of the samples were more yellow than others. Again, U.S. samples were approximately midway of all samples studied.

Long-grain.—The whitest samples—i.e., with highest "L" values—were from Portugal and Thailand, with "L" values above 70, closely followed by those from France, Italy, Mexico, and Turkey—all above the U.S. samples. Lowest "L" values were found in the India samples.

Medium-grain.—Samples from South Africa, Burma, West Germany, Greece, Philippine Islands, and Portugal were definitely lighter in color than U.S. medium-grain rices. On the other hand, those from India were consistently lower in "L" value than U.S. medium-grain samples.

Short-grain.—Again, India had among the lowest and the widest ranges of "L" values. U.S. short-grain was whiter than medium- or long-grain samples, mostly because of heavier milling pressures for the short-grain types.

TABLE 3.—BROKEN KERNELS: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	149	18. 2	0. 2–74. 3	136	23. 7	0. 8–72. 4	124	7. 3	0. 3–33. 1
U.S.A.									
Africa, South	2	5. 6	5. 2– 6. 0	1	13. 6		2	26. 0	21. 8–30. 2
Argentina	2	3. 8	3. 6– 3. 9	5	8. 6	3. 4–20. 5	4	9. 6	3. 8–23. 7
Australia							1	6. 2	
Brazil	7	20. 0	11. 8–41. 0	5	19. 8	9. 1–40. 9	3	10. 9	3. 6–14. 6
Burma	10	23. 6	13. 0–41. 3	35	27. 6	13. 9–41. 6			
Ceylon									
Chile									
Columbia	3	22. 4	11. 3–29. 7	1	30. 6				
Ecuador	2	5. 0	4. 1– 5. 9	4	21. 6	10. 2–38. 2			
Egypt							5	3. 9	1. 8– 8. 4
El Salvador	2	26. 6	21. 9–31. 3						
France	4	1. 4	. 5– 1. 9				2	2. 2	1. 6– 2. 9
Germany, West	5	10. 3	3. 8–26. 6	4	12. 5	1. 2–32. 0	3	8. 2	4. 6–11. 5
Ghana									
Greece	6	7. 3	. 2–13. 3	2	8. 6	4. 5–12. 8	8	5. 6	. 3–13. 8
Guatemala	2	21. 4	14. 0–28. 9						
India	20	15. 0	. 4–38. 1	21	24. 4	3. 2–38. 1	8	15. 6	6. 0–30. 5

Indonesia	10	65. 5	54. 1–74. 3	8	39. 8	21. 1–72. 4	4	18. 6	8. 4–26. 2
Iran	9	6. 2	. 2– 9. 6	5	23. 5	17. 9–30. 5	1	28. 2	----
Italy	6	. 8	. 2– 1. 4	----	----	----	3	2. 1	1. 8– 2. 3
Ivory Coast	1	41. 0	----	----	----	----	1	18. 3	----
Japan	6	13. 7	9. 7–17. 3	18	12. 6	. 8–27. 0	60	3. 5	. 5– 7. 9
Korea	----	----	----	----	----	----	10	11. 0	1. 7–33. 1
Mexico	9	13. 8	2. 4–41. 0	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----	----	----	----
Pakistan, East	----	----	----	----	----	----	----	----	----
Pakistan, West	11	21. 6	7. 0–62. 3	1	15. 2	----	----	----	----
Peru	6	24. 7	14. 8–34. 6	4	25. 9	12. 2–33. 0	----	----	----
Philippines	----	----	----	10	35. 6	28. 9–43. 2	----	----	----
Portugal	1	12. 9	----	3	26. 9	19. 2–34. 2	1	30. 3	----
Spain	----	----	----	----	----	----	5	12. 0	8. 5–14. 2
Thailand	24	15. 4	1. 0–46. 5	6	27. 8	9. 5–49. 9	----	----	----
Turkey	1	7. 1	----	3	6. 8	3. 8–10. 4	3	8. 1	4. 7–11. 1

Continued

TABLE 3.—BROKEN KERNELS: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	37	17.6	1.2–42.4	25	15.9	0.4–29.9
U.S.A.						
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	20.2	19.2–21.1	8	20.6	14.7–24.4
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	5.0	3.2– 6.8
Ghana	1	41.1				
Greece						
Guatemala						

India	6	14. 5	2. 1–28. 5	7	15. 0	. 4–28. 2
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria	1	44. 8				
Pakistan, East	6	27. 6	17. 5–42. 4	6	17. 7	7. 3–29. 9
Pakistan, West	6	29. 5	18. 0–39. 2			
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	5. 4	1. 2–13. 5	2	5. 8	5. 1– 6. 4
Turkey						

TABLE 4.—KERNEL COLOR: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		"L" values	*"L" values*		*"L" values*	*"L" values*		*"L" values*	*"L" values*
"All samples"	116	65.5	52.0–77.6	117	67.5	51.8–76.4	123	65.0	54.0–73.2
U.S.A.	6	66.2	64.7–67.6	5	65.8	64.6–67.2	2	70.8	70.4–71.3
Africa, South				1	74.1		2	64.0	56.9–71.2
Argentina				4	64.8	64.7–64.9	4	65.9	63.3–66.9
Australia							1	71.2	
Brazil	4	63.4	59.8–67.9	3	66.2	64.2–70.2	2	68.0	67.2–68.6
Burma	7	67.6	65.2–70.8	23	72.3	69.8–76.4			
Ceylon									
Chile									
Colombia									
Ecuador	1	67.3		3	69.2	68.9–69.4			
Egypt							5	66.3	54.0–71.0
El Salvador									
France	4	69.5	68.9–70.4				2	71.0	70.3–72.0
Germany, West	5	64.5	59.0–71.7	4	70.9	66.8–73.9	3	70.6	68.7–73.2
Ghana									
Greece	6	66.4	64.0–69.0	2	71.0	69.7–72.4	8	69.5	65.2–72.6
Guatemala									

India	15	60. 4	52. 0–65. 1	17	60. 8	51. 8–67. 4	6	62. 9	55. 8–69. 6
Indonesia	12	64. 7	61. 0–68. 4	8	68. 7	75. 3–71. 9	4	67. 4	66. 3–68. 4
Iran	3	64. 4	63. 8–64. 8	5	62. 9	62. 0–63. 5	1	61. 7	----------
Italy	6	68. 4	67. 3–69. 0	------	------	----------	3	65. 8	65. 2–66. 2
Ivory Coast	------	------	----------	------	------	----------	1	68. 1	----------
Japan	6	65. 9	64. 4–67. 2	18	67. 6	60. 8–73. 2	60	63. 2	57. 9–66. 6
Korea	------	------	----------	------	------	----------	10	64. 2	57. 1–69. 0
Mexico	8	68. 9	66. 6–72. 1	------	------	----------	------	------	----------
Nigeria	------	------	----------	------	------	----------	------	------	----------
Pakistan, East	------	------	----------	------	------	----------	------	------	----------
Pakistan, West	11	61. 9	60. 4–63. 1	1	61. 6	----------	------	------	----------
Peru	6	63. 7	62. 4–66. 4	4	62. 8	61. 1–65. 8	------	------	----------
Philippines	------	------	----------	9	70. 3	69. 6–71. 7	------	------	----------
Portugal	1	71. 4	----------	3	71. 3	68. 5–72. 5	1	73. 4	----------
Spain	------	------	----------	------	------	----------	5	68. 6	63. 9–71. 9
Thailand	11	70. 0	65. 3–77. 6	4	65. 8	62. 6–69. 6	------	------	----------
Turkey	1	68. 6	----------	3	66. 1	65. 1–67. 7	3	62. 9	62. 3–63. 4

Continued

TABLE 4.—KERNEL COLOR: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		"L" values	*"L" values*		*"L" values*	*"L" values*
"All samples"	21	55. 1	45. 5–65. 7	15	50. 8	44. 4–59. 2
U.S.A.	1	60. 4				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	57. 4	56. 6–58. 0			
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	56. 5	53. 3–59. 2
Ghana	1	50. 6				
Greece						
Guatemala						

India	3	54.1	53.0–55.2	5	51.7	48.4–53.9
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	3	46.0	45.5–46.8	6	45.5	44.4–47.2
Pakistan, West	6	56.3	48.1–65.7			
Peru						
Philippines						
Portugal						
Spain						
Thailand	4	58.8	55.6–61.8	2	58.4	57.8–58.9
Turkey						

Parboiled Milled Rice

As expected, the parboiled rices showed lower "L" values than did the milled rices. The number of parboiled samples was too small to make sound conclusions, but generally it was observed that the Burma and Thailand samples were about equal to the U.S. sample whereas those from India, East Pakistan, and West Pakistan were darker than the U.S. sample. Parboiled samples were more yellow than the raw milled ones.

Thermal and Chemical Reactions

Cooking qualities rank high among consumers' criteria in choosing rice for the table. Therefore, any test that measures the behavior of rice or its components when heated in water, being directly related to common cooking procedures, should yield values highly useful in comparing rices as to this their major use. An important effect of moist heat on rice is the swelling and solubilization of starch, which leads to such changes as increase in volume, splitting and fragmentation or sloughing, and the development of various textural qualities. In this study, several of the determinations were built around the reactions of rice to heat, including temperatures at which aqueous suspensions of starch show a sudden rise in viscosity (gelatinization temperature); visible changes occurring in individual starch granules when heated to 62° C. (heat alteration values); absorption of water by kernels heated to 77° C. or 82° C. (water uptake); loss of solids from kernels when heated to 77° C. or 82° C. (sedimentation values); and leaching of amylose from kernels when heated to 77° C. (iodine-blue values). All of these tests except the iodine-blue are discussed in this section; iodine-blue will be discussed along with starch determinations.

Gelatinization Temperature

Gelatinization is the transformation through hydration of the small, high-density, opaque or white starch granules into large, fragile, translucent, gelatinous bodies of low density, usually with considerable loss of soluble material and release of some nonsoluble material through rupture of the granules to the water. When appropriate amounts of starch are stirred while being heated in water, the suspension becomes a translucent paste with greatly increased viscosity beginning at some fairly definite point in the temperature scale. Gelatinization temperatures for rice varieties as determined with the aid of an amylograph, have been reported to range from 58° C. to 80° C. (*16*).

The range of gelatinization temperatures for most of the samples examined was from about 60° C. to 75° C., as shown in table 5. U.S.

rices had greatest gelatinization temperature values in long-grain samples, medium-grain samples were next, and the short-grain rices had the least. Short-grain foreign-milled rices exhibited the lowest average gelatinization temperatures. Consistency of pattern between long- and medium-grain foreign-milled rices was not apparent. The one long-grain milled-rice sample examined from the Ivory Coast showed the highest absolute gelatinization temperature (78° C.) of the rices tested. Those from Brazil yielded the greatest range (23° C.), and one of these had the lowest gelatinization temperature (50.5° C.).

On the average, ranges in gelatinization temperature were less for the short-grain type than for the other two grain types (table 5).

Milled Rice

There is a high negative correlation between gelatinization temperature and the related group of alkali spreading, alkali clearing, heat alteration, and water uptake at 77° C. (table 27). Confirming this trend is the indication of a positive correlation between gelatinization temperature and the amylose/amylopectin ratio.

The positive correlation for combined "all samples," regardless of grain length, between gelatinization temperature and cooking quality cohesiveness seems to justify more detailed studies of this relationship in specific grain-length categories.

Long-grain.—Gelatinization temperature for U.S. samples corresponded to the average for all samples, with those from Argentina, France, Greece, Italy, Portugal, and Turkey being lowest. Those from Ivory Coast, Ecuador, Indonesia, and West Pakistan were among the highest. The varieties from Mexico were the least and those from Brazil the most variable.

Medium-grain.—Gelatinization temperatures of samples from the United States, Japan, Peru, Portugal, and Turkey were much lower than the general average. Only samples from Portugal and Turkey had lower values than those from the United States. The samples from Ceylon, Ecuador, Portugal, the Philippines, and India were the least, and those from Japan varied the most.

Short-grain.—The average values for samples from each country were exceedingly close, ranging from 60.0° C. to 63.8° C., except two from India that were 72.0° C. Average gelatinization temperature for short-grain rices was substantially lower than that for long- and for medium-grain samples.

Parboiled Milled Rice

Since parboiling gelatinizes starch, the gelatinization temperature test was not made on the parboiled samples.

TABLE 5.—GELATINIZATION TEMPERATURE: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		°C.	°C.		°C.	°C.		°C.	°C.
"All samples"	70	70.1	50.5–78.0	70	70.2	57.0–76.5	40	62.4	57.0–72.0
U.S.A.	6	70.8	66.0–75.0	5	64.5	61.5–67.5	2	63.0	63.0–63.0
Africa, South	2	69.8	69.0–70.5				2	63.8	63.0–64.5
Argentina	1	64.5		1	75.0		1	61.5	
Australia							1	60.0	
Brazil	5	66.2	50.5–73.5	5	70.3	66.0–73.5	2	63.0	63.0–63.0
Burma	2	70.5	66.0–75.0	10	71.6	69.0–75.0			
Ceylon				2	75.0	75.0–75.0			
Chile									
Colombia	3	72.0	69.0–73.5	1	70.5				
Ecuador	2	73.5	72.0–75.0	3	71.5	70.5–72.0			
Egypt							2	60.8	60.0–61.5
El Salvador	2	72.0	70.5–73.5						
France	2	63.8	60.0–67.5						
Germany, West	5	69.3	60.0–73.5	4	69.0	64 5–73.5	3	62.0	60.0–63.0
Ghana									
Greece	1	63.0					1	61.5	
Guatemala	2	71.2	70.5–72.0						

India	8	72.0	70.5–75.0	11	73.8	72.0–75.0	3	70.5	67.5–72.0
Indonesia	6	73.8	72.0–76.5	4	72.8	66.0–76.5	2	63.8	63.0–64.5
Iran	1	72.0	------	1	72.0	------	1	63.0	------
Italy	2	63.0	63.0–63.0	------	------	------	1	60.0	------
Ivory Coast	1	78.0	------	------	------	------	1	63.0	------
Japan	1	70.5	------	6	65.5	60.0–72.0	8	60.8	57.0–63.0
Korea	------	------	------	------	------	------	4	60.4	58.5–63.0
Mexico	9	72.0	70.5–73.5	------	------	------	------	------	------
Nigeria	------	------	------	------	------	------	------	------	------
Pakistan, East	------	------	------	------	------	------	------	------	------
Pakistan, West	3	75.0	72.0–76.5	------	------	------	------	------	------
Peru	------	------	------	1	66.0	------	------	------	------
Philippines	------	------	------	8	72.6	72.0–73–5	------	------	------
Portugal	1	60.0	------	3	60.5	60.0–61.5	1	60.0	------
Spain	------	------	------	------	------	------	2	62.2	60.0–64.5
Thailand	4	65.6	60.0–69.0	3	74.0	72.0–75.0	------	------	------
Turkey	1	60.0	------	2	60.0	57.0–63.0	3	62.5	61.5–63.0

Heat Alteration

The heat alteration test constitutes another method of measuring the probable gelatinization potential of rice starches. In this method, individual starch granules, which have been heated in water at a fixed temperature (62° C.), are observed microscopically with phase contrast illumination, and scored as to degree of change from the natural or unheated appearance. In any one sample, the alteration in individual granules appears to begin at different temperatures within a short range, and to require a slight temperature rise for completion, so that only in rare cases (extremes) do all granules have a similar appearance. Therefore, in a study of this kind, granules are seen in many forms or stages of change, ranging from the unaltered (small, dense, hard, angular, luminous, crystalloid bodies—characteristic of unheated controls) to the completely "darkened" (greatly enlarged, thin, distended, soft, of low density, gelatinous nonluminous spheres that are easily flattened and ruptured). The gelatinization potential of a sample is thought to be indicated by the extent of change observed in a majority of its starch granules. In the previous study *(30)* it was observed that samples of known high gelatinization temperatures showed few granules slightly altered (low heat-alteration values), and low gelatinization temperatures showed most granules greatly altered (high heat-alteration values).

These studies revealed a consistent relation between heat alteration and gelatinization temperature for total, long-, medium-, and short-grain types of rice (table 27).

There was a high degree of positive correlation (table 27) between heat alteration and the quality factors alkali spreading, alkali clearing, and water uptake at 77° C. There was some correlation, but much less, between heat alteration and water uptake at 82° C.

Milled Rice

Ranges of heat alteration values for long-, medium-, and short-grain milled rices were strikingly similar (table 6). Average values were different, however; for the short-grain varieties, average values were about three times that for long- and medium-grain rices. These differences, which indicate a low gelatinization temperature for short-grain varieties, may explain, in part, why short-grain rices exhibit greater cohesiveness than the other two types.

Long-grain.—Samples from Greece and Italy had high heat alteration values, averaging 2.5 and 2.4, respectively. Samples from the United States, Brazil, Burma, and West Germany had values near the average for this group. Those from Colombia, Ecuador, Indonesia, Iran, Mexico, and East Pakistan had the lowest values.

Medium-grain.—The average value for medium rices was probably unduly weighted by the large number of low-value samples from Burma, India, and Philippine Islands. Highest averages were in the samples from United States, Japan, Peru, and Portugal.

Short-grain.—The short-grain India samples, like the India long- and medium-grain, had exceedingly low values (0.2–0.4). The other short-grain rices had a range between 1.8 and 2.9.

Parboiled Milled Rice

Parboiled long- and medium-grain rices had about the same heat alteration average values and range as did the corresponding milled samples. Based on the results of this investigation, there was little differentiation between milled and parboiled milled rices of similar lengths, by the heat alteration test.

Parboiling induces a certain amount of heat alteration in rices, varying from slight to great, depending both on the type of rice and on the parboiling conditions. For these reasons, heat alteration determinations on parboiled samples cannot be interpreted in the same way as those made on raw milled rices.

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TABLE 6.—HEAT ALTERATION: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Values	*Values*		*Values*	*Values*		*Values*	*Values*
"All samples"	72	. 7	0. 1–2. 6	73	0. 7	0. 1–2. 8	74	2. 3	0. 2–2. 9
U.S.A.	6	. 7	. 1–2. 4	5	2. 0	1. 2–2. 8	2	2. 2	2. 2–2. 2
Africa, South									
Argentina				1	. 1		3	2. 5	2. 3–2. 8
Australia							1	2. 7	
Brazil	4	1. 0	. 2–2. 4	3	1. 4	. 4–2. 4	2	2. 5	2. 4–2. 6
Burma	5	. 9	. 2–1. 5	13	. 3	. 1– . 8			
Ceylon									
Chile									
Colombia	3	. 2	. 2– . 3						
Ecuador	1	. 2		3	. 2	. 2– . 2			
Egypt							1	2. 6	
El Salvador									
France							2	2. 6	2. 6–2. 6
Germany, West	2	. 9	. 6–1. 2				1	2. 2	
Ghana									
Greece	3	2. 5	2. 3–2. 6				2	2. 6	2. 5–2. 6

Guatemala									
India	15	.4	.1–1.0	18	.2	.1–1.1	7	.3	.2–.4
Indonesia	8	.3	.1–.5	5	.4	.2–.6	3	2.2	2.2–2.2
Iran	3	.3	.2–.4	5	1.3	.4–2.6	1	2.4	
Italy	2	2.4	2.3–2.4				1	2.8	
Ivory Coast									
Japan				5	2.6	2.4–2.8	38	2.5	1.8–2.9
Korea							6	2.7	2.4–2.9
Mexico	5	.3	.1–.5						
Nigeria									
Pakistan, East	4	.2	.1–.4						
Pakistan, West	4	.4	.2–.6						
Peru				1	2.4				
Philippines				9	.2	.1–.4			
Portugal				2	2.4	2.2–2.7			
Spain							2	2.2	2.2–2.3
Thailand	5	1.3	.2–2.5	3	.4	.1–.6			
Turkey							2	2.6	2.5–2.7

Continued

TABLE 6.—HEAT ALTERATION: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Values	*Values*		*Values*	*Values*
"All samples"	14	0. 7	0. 4–1. 6	13	0. 7	0. 2–1. 1
U.S.A.	1	. 9				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	1	. 6				
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	. 6	. 4– . 8

Ghana						
Greece						
Guatemala						
India	3	.6	.4–.8	5	.6	.3–1.1
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	4	.7	.6–.8	4	.7	.5–.8
Pakistan, West	2	.8	.5–1.2			
Peru						
Philippines						
Portugal						
Spain						
Thailand	4	.9	.4–1.6	2	.8	.5–1.0
Turkey						

Water Uptake and Sedimentation Values

Water uptake and sedimentation values are interrelated, as evidenced by the method of determination. These tests, under various conditions of temperature and time, have been rather widely accepted as indicative of cooking qualities and perhaps other characteristics.

Water uptake is a measure of the hydration characteristics of a rice, which may be influenced by such factors as the gelatinization temperature and the porosity of the kernel. Processing of rice—for example, parboiling—also changes the sorptive capacity of rices and radically alters their hydration characteristics. Many researchers (*16*, *37*) believe that the hydration characteristics are indicative of the degree of intermolecular association, on the assumption that free hydroxyl groups must be available for the attachment of water.

The sedimentation test is a measure of the insoluble solids lost to the treating solution at the specified temperature. It is influenced by the gelatinization temperature and the physical structure of the kernel.

In general, water uptake and sedimentation tests give an insight into the behavior of short-grain rices during cooking, since they absorb more water and give greater sediment at the temperatures used than do either the long- or medium-grain rices.

It is to be noted that average values, for the "all samples," for long- and medium-grain milled rices under each heading are fairly close, whereas those for the short grains are considerably higher. However, because water uptake and sedimentation values vary widely even within a single grain length, average values are not particularly meaningful.

Water Uptake at 77° C.

Milled Rice

There was a high positive correlation (table 27) between water uptake at 77° C. and heat alteration. On the other hand, high negative correlations were found between water uptake and gelatinization temperatures (*16*). There was good evidence of a positive correlation between water uptake and amylopectin content and a negative correlation for water uptake with amylose and the amylose/amylopectin ratio. Cooking quality cohesiveness was negatively correlated with water uptakes for "all samples" and medium-grain rices.

There was a positive correlation between water uptake and sedimentation, with a higher degree of correlation in the sedimentation test made at 77° C.

As expected, there was a high positive correlation between both alkali spreading and alkali clearing and water uptake for the "all samples" of the categories of total, long-, medium-, and short-grain lengths.

Long-grain.—U.S. samples were close to the "all samples" average and range. Samples from Argentina, France, Greece, Italy, Portugal, and Turkey were the highest in these values, with those from Ecuador and El Salvador being the lowest (table 7).

Medium-grain.—Although the "all samples" average values were near those for long-grain samples, examination of the data for the samples from the individual country would indicate this was more of a mathematical coincidence.

Short-grain.—For the most part, short-grain rices had higher water-uptake values and a wider range than the long- and medium-grain types had.

Parboiled Milled Rice

As expected, parboiling caused the rices to have lowered total water absorption and to have a narrower range of variation than the raw samples. Parboiling seemed to make the water-uptake values more nearly the same for both long- and medium-grain rices.

Sedimentation at 77° C.

Milled Rice

Sedimentation values for milled rices followed the same patterns as the water-uptake determinations at this same temperature—higher values and wider range of variation for the short-grain samples.

A positive correlation (table 27) existed for the milled-rice samples between sedimentation values at 77° C. and at 82° C. To a lesser extent, there was a positive correlation between sedimentation at 77° C. and alkali spreading, alkali clearing, and water uptake at this temperature.

One unique observation was that the samples from Greece—in all categories of long-, medium-, and short-grain samples—had the highest sedimentation values of any of the 34 countries considered (table 8).

Long-grain.—Samples from three countries—Greece, Italy, and Portugal—had much higher sedimentation values than the average for the 34 countries. On the other hand, samples from Ecuador, Iran, and West Pakistan had very low values for this determination. Indonesia and India samples had the widest range of values.

Medium-grain.—Samples from Greece and Turkey had highest sedimentation values; those from Ceylon, India, Indonesia, and Peru, lowest.

Short-grain.—Samples from South Africa, Egypt, and Greece had very high values.

Parboiled Milled Rice

The sedimentation values reveal marked differences between milled and parboiled samples. Sediment for parboiled samples was about one-fourth that for milled rices.

TABLE 7.—WATER UPTAKE AT 77° C.: *Number of samples, mean, and range of values for each country and for "all samples"*

[Water absorbed by 100 grams of rice]

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*		*Ml.*	*Ml.*
"All samples"	167	175	66–353	149	182	60–367	128	278	91–441
U.S.A.	6	163	66–326	5	255	217–283	2	257	247–267
Africa, South	2	190	161–220	1	124	---	2	358	321–395
Argentina	2	274	269–278	5	129	104–211	4	259	232–274
Australia	---	---	---	---	---	---	1	292	---
Brazil	7	158	105–275	5	185	116–278	3	309	268–338
Burma	11	202	138–284	35	166	109–256	---	---	---
Ceylon	---	---	---	7	123	87–157	3	130	91–172
Chile	---	---	---	---	---	---	---	---	---
Colombia	4	158	107–195	1	185	---	---	---	---
Ecuador	2	84	72– 97	4	157	98–182	---	---	---
Egypt	---	---	---	---	---	---	4	318	296–352
El Salvador	2	123	94–152	---	---	---	---	---	---
France	4	304	283–312	---	---	---	2	314	310–318
Germany, West	5	198	139–274	4	216	131–331	3	274	185–331
Ghana	---	---	---	---	---	---	---	---	---

Greece	6	297	287–306	2	294	277–312	8	297	263–336
Guatemala	2	157	150–164	---	---	---	---	---	---
India	20	149	98–207	21	153	60–289	8	160	109–287
Indonesia	18	127	66–209	8	112	66–202	4	306	294–328
Iran	9	142	124–153	5	207	130–314	1	248	---
Italy	6	299	265–343	---	---	---	3	305	287–335
Ivory Coast	1	180	---	---	---	---	1	336	---
Japan	6	156	118–201	18	231	148–322	60	280	156–441
Korea	---	---	---	---	---	---	10	295	275–325
Mexico	9	156	117–220	---	---	---	---	---	---
Nigeria	---	---	---	---	---	---	---	---	---
Pakistan, East	---	---	---	---	---	---	---	---	---
Pakistan, West	11	124	90–183	1	145	---	---	---	---
Peru	6	161	148–170	4	190	163–215	---	---	---
Philippines	---	---	---	11	187	144–256	---	---	---
Portugal	1	307	---	3	340	323–367	1	348	---
Spain	---	---	---	---	---	---	5	308	299–325
Thailand	26	184	85–353	6	172	132–243	---	---	---
Turkey	1	302	---	3	303	292–320	3	320	307–327

Continued

TABLE 7.—WATER UPTAKE AT 77° C.: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

[Water absorbed by 100 grams of rice]

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*
"All samples"	37	133	89–192	26	135	93–181
U.S.A	1	195				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	119	110–127	8	108	93–134
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	179	178–180
Ghana	1	163				

Greece	--	--	--	--	--	--
Guatemala	--	--	--	--	--	--
India	6	126	89–184	7	139	102–167
Indonesia	--	--	--	--	--	--
Iran	--	--	--	--	--	--
Italy	--	--	--	--	--	--
Ivory Coast	--	--	--	--	--	--
Japan	--	--	--	--	--	--
Korea	--	--	--	--	--	--
Mexico	--	--	--	--	--	--
Nigeria	1	153	--	--	--	--
Pakistan, East	6	147	107–173	6	153	120–181
Pakistan, West	6	117	96–141	--	--	--
Peru	--	--	--	--	--	--
Philippines	--	--	--	--	--	--
Portugal	--	--	--	--	--	--
Spain	--	--	--	--	--	--
Thailand	13	133	94–192	3	128	108–142
Turkey	--	--	--	--	--	--

TABLE 8.—SEDIMENT AT 77° C.: *Number of samples, mean, and range of values for each country and for "all samples"*

[From 100 grams of rice]

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*		*Ml.*	*Ml.*
"All samples"	167	17.3	1.5–66.0	149	17.6	1.0–53.0	128	26.5	2.0–93.0
U.S.A.	6	12.2	8.0–19.5	5	26.9	14.5–44.5	2	44.5	40.5–48.5
Africa, South	2	28.5	18.0–39.0	1	20.0	----	2	60.0	36.0–84.0
Argentina	2	26.2	25.0–27.5	5	18.0	11.0–25.0	4	19.5	15.5–28.5
Australia	----	----	----	----	----	----	1	42.5	----
Brazil	7	16.2	10.5–24.0	5	24.0	12.0–34.0	3	34.3	27.0–40.0
Burma	11	13.0	7.0–22.5	35	21.1	9.0–34.0	----	----	----
Ceylon	----	----	----	7	5.1	1.0–12.0	3	4.0	2.0– 6.0
Chile	----	----	----	----	----	----	----	----	----
Colombia	4	13.2	10.5–18.5	1	16.0	----	----	----	----
Ecuador	2	5.8	3.0– 8.5	4	12.4	7.0–23.0	----	----	----
Egypt	----	----	----	----	----	----	4	63.8	31.0–93.0
El Salvador	2	10.5	3.5–17.5	----	----	----	----	----	----
France	4	21.4	18.5–25.5	----	----	----	2	20.0	15.0–25.0
Germany, West	5	19.4	10.0–42.0	4	17.1	7.5–28.0	3	42.7	27.5–65.0
Ghana	----	----	----	----	----	----	----	----	----

Greece	6	61.0	44.5–66.0	2	52.8	52.5–53.0	8	60.1	44.0–81.0
Guatemala	2	20.5	20.5–20.5	------	------	------	------	------	------
India	20	10.2	1.5–55.0	21	9.5	2.0–26.5	8	8.3	3.0–25.5
Indonesia	18	17.0	4.0–46.0	8	8.5	3.0–15.0	4	18.4	16.0–20.0
Iran	9	9.6	6.0–20.0	5	15.9	13.5–21.0	1	25.0	------
Italy	6	33.2	19.0–51.0	------	------	------	3	15.7	14.5–16.5
Ivory Coast	1	16.0	------	------	------	------	1	41.0	------
Japan	6	17.5	1.5–28.0	18	23.2	13.5–37.0	60	20.4	11.5–43.0
Korea	------	------	------	------	------	------	10	28.6	19.0–43.0
Mexico	9	20.4	12.0–34.0	------	------	------	------	------	------
Nigeria	------	------	------	------	------	------	------	------	------
Pakistan, East	------	------	------	------	------	------	------	------	------
Pakistan, West	11	8.3	2.5–20.5	1	24.0	------	------	------	------
Peru	6	13.8	10.0–17.5	4	8.0	3.0–16.0	------	------	------
Philippines	------	------	------	11	16.2	13.0–23.5	------	------	------
Portugal	1	41.0	------	3	26.7	15.5–38.5	1	28.5	------
Spain	------	------	------	------	------	------	5	32.1	24.5–43.5
Thailand	26	16.4	4.5–60.0	6	16.3	11.0–26.0	------	------	------
Turkey	1	32.5	------	3	33.8	25.5–48.0	3	28.8	28.0–30.0

Continued

TABLE 8.—SEDIMENT AT 77° C.: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

[From 100 grams of rice]

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*
"All samples"	37	4. 2	0. 5–20. 0	26	4. 7	1. 5–20. 0
U.S.A	1	1. 5				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	5. 7	5. 0– 6. 0	8	6. 5	2. 0–20. 0
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	2. 8	2. 5– 3. 0
Ghana	1	12. 0				

Greece	---	---	---	---	---	---
Guatemala	---	---	---	---	---	---
India	6	1. 9	. 5– 2. 5	7	3. 2	1. 5– 5. 5
Indonesia	---	---	---	---	---	---
Iran	---	---	---	---	---	---
Italy	---	---	---	---	---	---
Ivory Coast	---	---	---	---	---	---
Japan	---	---	---	---	---	---
Korea	---	---	---	---	---	---
Mexico	---	---	---	---	---	---
Nigeria	1	6. 0	---	---	---	---
Pakistan, East	6	3. 1	2. 5– 3. 5	6	3. 7	1. 5– 6. 5
Pakistan, West	6	8. 8	1. 5–20. 0	---	---	---
Peru	---	---	---	---	---	---
Philippines	---	---	---	---	---	---
Portugal	---	---	---	---	---	---
Spain	---	---	---	---	---	---
Thailand	13	2. 9	2. 0– 5. 5	3	6. 3	2. 0– 9. 5
Turkey	---	---	---	---	---	---

Water Uptake at 82° C.

Milled Rice

Correlation between water uptake at 82° C. and gelatinization temperature, heat alteration, alkali spreading, and alkali clearing is lower than correlation between water uptake at 77° C. and these same quality factors (table 27).

Since 82° C. is higher than the gelatinization temperature of most rices, the water uptake for long-, medium-, and short-grain samples was nearer the same values at this temperature than when determined at 77° C. However, there was an increasingly wider range of values from long-, to medium-, to short-grain classes (table 9).

Long-grain.—The average for U.S. samples was close to that for all the countries, but one U.S. sample was considerably higher than any other tested. The samples from India and Japan were among the lowest in such values, although the samples from Japan averaged near the median for this class.

Medium-grain.—Whereas samples from Ceylon, Indonesia, and India averaged least, U.S. samples were typical for this group. Samples from Colombia, the Philippines, and Portugal averaged considerably above the others.

Short-grain.—Except for Portugal, all countries averaged higher for this test at 82° C. than at 77° C.

Parboiled Milled Rice

For parboiled milled rices, the average water uptake was 65 percent higher at 82° C. than at 77° C. Even so, there was a narrower range in water uptake values at 82° C. than at 77° C.

Sedimentation at 82° C.

In general, for all three grain-length types, sedimentation values at 82° C. were substantially greater than those obtained at 77° C. (table 10).

Milled Rice

There is evidence of substantial negative correlation between sediment at 82° C. and cooking quality cohesiveness, although not quite as definite as when tested at 77° C. (See table 27.) All grain types from India had very low sedimentation values and would warrant further study to determine the reason for this behavior.

Long-grain.—Here again, U.S. rice corresponded to the average sedimentation value for all long-grain samples. Samples from Greece were unique in having by far the highest average. The long-grain milled samples from Thailand had much the greatest range from low to high values for any type of rice, milled or parboiled milled, from any country.

Medium-grain.—Samples from Ceylon, India, and Peru had exceedingly low values. Samples from Greece again had the highest values.

Short-grain.—Rices from India had the lowest values.

Parboiled Milled Rice

Parboiled milled samples had only slightly higher sedimentation values at 82° C. than at 77° C.; these values were only about a third of those for any of the milled samples.

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TABLE 9.—WATER UPTAKE AT 82° C.: *Number of samples, mean, and range of values for each country and for "all samples"*

[Water absorbed by 100 grams of rice]

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*		*Ml.*	*Ml.*
"All samples"	167	312	180–443	149	299	111–445	129	336	139–529
U.S.A.	6	316	220–443	5	320	282–352	2	324	323–325
Africa, South	2	380	345–415	1	291		2	378	373–383
Argentina	2	318	310–325	5	296	270–352	4	313	295–322
Australia							1	322	
Brazil	7	326	222–374	5	300	249–341	3	348	328–366
Burma	11	305	256–394	35	305	231–404			
Ceylon				7	195	111–284	3	204	139–241
Chile									
Colombia	4	316	260–355	1	359				
Ecuador	2	235	232–238	4	320	277–358			
Egypt							5	384	357–414
El Salvador	2	297	237–357						
France	4	330	316–344				2	331	328–334
Germany, West	5	278	265–288	4	308	286–354	3	399	319–529
Ghana									

Greece	6	334	303–363	2	290	247–332	8	374	358–393
Guatemala	2	338	331–345	-----	-----	-----	-----	-----	-----
India	20	273	180–328	21	280	122–367	8	297	201–377
Indonesia	18	300	217–357	8	250	164–356	4	348	328–367
Iran	9	313	299–328	5	306	288–344	1	318	-----
Italy	6	357	331–382	-----	-----	-----	3	366	344–406
Ivory Coast	1	267	-----	-----	-----	-----	1	381	-----
Japan	6	320	185–359	18	326	290–360	60	335	275–502
Korea	-----	-----	-----	-----	-----	-----	10	325	303–350
Mexico	9	361	272–415	-----	-----	-----	-----	-----	-----
Nigeria	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, East	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, West	11	264	203–309	1	291	-----	-----	-----	-----
Peru	6	316	272–359	4	317	284–355	-----	-----	-----
Philippines	-----	-----	-----	11	395	337–445	-----	-----	-----
Portugal	1	356	-----	3	366	363–370	1	333	-----
Spain	-----	-----	-----	-----	-----	-----	5	338	316–361
Thailand	26	334	275–415	6	342	310–386	-----	-----	-----
Turkey	1	326	-----	3	334	317–351	3	343	335–357

Continued

TABLE 9.—WATER UPTAKE AT 82° C.: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

[Water absorbed by 100 grams of rice]

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*
"All samples"	37	231	169–334	26	214	144–289
U.S.A	1	298				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	188	178–194	8	172	144–268
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	208	202–215
Ghana	1	230				

Greece						
Guatemala						
India	6	206	169–268	7	216	181–246
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria	1	220				
Pakistan, East	6	236	215–250	6	253	217–272
Pakistan, West	6	289	228–334			
Peru						
Philippines						
Portugal						
Spain						
Thailand	13	218	175–276	3	251	197–289
Turkey						

TABLE 10.—SEDIMENT AT 82° C.: *Number of samples, mean, and range of values for each country and for "all samples"*

[From 100 grams of rice]

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*		*Ml.*	*Ml.*
"All samples"	167	23. 4	1. 5–73. 0	149	21. 9	1. 5–58. 0	129	25. 4	1. 5–55. 5
U.S.A.	6	24. 8	15. 5–28. 5	5	27. 6	20. 5–44. 0	2	35. 2	33. 5–37. 0
Africa, South	2	33. 0	32. 0–34. 0	1	45. 0	-----------	2	34. 5	31. 0–38. 0
Argentina	2	45. 2	41. 0–49. 5	5	28. 4	26. 0–32. 0	4	25. 5	24. 5–26. 5
Australia	-------	-------	-----------	-------	-------	-----------	1	57. 5	-----------
Brazil	7	25. 9	18. 0–32. 0	5	37. 6	11. 0–58. 0	3	33. 7	28. 0–41. 0
Burma	11	14. 5	10. 0–21. 0	35	23. 8	11. 0–43. 0	-------	-------	-----------
Ceylon	-------	-------	-----------	7	7. 9	1. 5–16. 0	3	7. 0	1. 5–14. 0
Chile	-------	-------	-----------	-------	-------	-----------	-------	-------	-----------
Colombia	4	26. 0	16. 0–32. 5	1	26. 0	-----------	-------	-------	-----------
Ecuador	2	10. 5	8. 0–13. 0	4	18. 0	13. 5–27. 5	-------	-------	-----------
Egypt	-------	-------	-----------	-------	-------	-----------	5	39. 2	31. 0–47. 0
El Salvador	2	16. 8	10. 5–23. 0	-------	-------	-----------	-------	-------	-----------
France	4	29. 6	20. 5–47. 5	-------	-------	-----------	2	15. 8	15. 0–16. 5
Germany, West	5	28. 4	16. 0–55. 0	4	23. 9	7. 5–33. 5	3	40. 5	36. 5–45. 5
Ghana	-------	-------	-----------	-------	-------	-----------	-------	-------	-----------

Greece	6	50.4	33.0–73.0	2	46.2	39.0–53.5	8	42.1	30.0–55.5
Guatemala	2	29.8	26.0–33.5						
India	20	12.4	1.5–27.5	21	12.0	1.5–23.0	8	10.9	5.5–16.5
Indonesia	18	30.4	15.0–58.0	8	23.1	7.5–38.5	4	24.1	16.0–35.5
Iran	9	16.7	11.5–22.5	5	22.9	20.0–24.0	1	22.5	
Italy	6	31.2	27.5–36.5				3	20.0	18.0–22.5
Ivory Coast	1	21.0					1	39.0	
Japan	6	24.2	5.0–38.0	18	26.0	12.5–38.5	60	21.6	13.0–42.5
Korea							10	25.6	15.0–36.5
Mexico	9	32.9	22.0–46.0						
Nigeria									
Pakistan, East									
Pakistan, West	11	14.5	2.5–27.5	1	22.5				
Peru	6	13.2	11.0–17.5	4	9.9	2.5–17.5			
Philippines				11	17.1	14.5–21.5			
Portugal	1	24.0		3	26.0	20.5–36.0	1	45.0	
Spain							5	32.4	25.0–39.0
Thailand	26	22.9	4.0–61.0	6	23.8	19.5–29.0			
Turkey	1	35.0		3	28.0	21.0–41.0	3	37.5	31.5–42.5

Continued

TABLE 10.—SEDIMENT AT 82° C.: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

[From 100 grams of rice]

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Ml.	*Ml.*		*Ml.*	*Ml.*
"All samples"	37	7.6	0.5–23.5	26	7.5	2.0–22.0
U.S.A	1	3.5				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	13.7	11.0–18.0	8	12.1	6.0–22.0
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	4.0	2.5– 5.5
Ghana	1	22.0				

Greece	—	—	—	—	—	—
Guatemala	—	—	—	—	—	—
India	6	3. 9	0. 5– 6. 0	7	3. 9	2. 0– 6. 5
Indonesia	—	—	—	—	—	—
Iran	—	—	—	—	—	—
Italy	—	—	—	—	—	—
Ivory Coast	—	—	—	—	—	—
Japan	—	—	—	—	—	—
Korea	—	—	—	—	—	—
Mexico	—	—	—	—	—	—
Nigeria	1	12. 0	—	—	—	—
Pakistan, East	6	5. 5	4. 5– 7. 5	6	4. 9	2. 0– 8. 5
Pakistan, West	6	11. 0	2. 0–23. 5	—	—	—
Peru	—	—	—	—	—	—
Philippines	—	—	—	—	—	—
Portugal	—	—	—	—	—	—
Spain	—	—	—	—	—	—
Thailand	13	6. 2	2. 5–11. 5	3	11. 2	6. 5–15. 0
Turkey	—	—	—	—	—	—

Alkali Spreading and Clearing

Alkali spreading and clearing values represent the reactions of milled rice kernels to soaking in dilute alkali. In previous studies (*24*, *31*, *44*), alkali reactions were shown to be roughly indicative of textural qualities in the cooked rice. Varietal differences in starch granules can be determined with the alkali test.

Alkali spreading and clearing values parallel each other quite closely, since they represent separate measurements of a single test (tables 11 and 12). There is sometimes an advantage in having evaluated the reaction by two subjective scoring systems rather than one.

Generally, in the alkali spreading tests, milled short-grain varieties spread more extensively than medium-grain, and medium-grain spread more than long-grain. This was true for both domestic and foreign rices.

Milled Rice

Some interesting relationships were shown in the consistent pattern of alkali spreading and alkali clearing, being negatively correlated with amylose, amylose/amylopectin ratio, and gelatinization temperature (table 27). And the converse: Alkali spreading and alkali clearing showed high positive correlation with amylopectin, water uptake, sediment, and heat alteration. A higher degree of correlation was found at 77° C. than at 82° C. for both water uptake and sediment.

There were strong negative correlations between alkali spreading and gelatinization temperature values, with the degree of negative correlation increasing from long-grain to short-grain types.

Long-grain.—Most of the long-grain samples had high average values for alkali spreading, with about one-third averaging above the U.S. rices. Most of the samples from each country had a relatively narrow range of values.

U.S. samples showed the widest range of values for the alkali clearing evaluations. Over 80 percent of all samples tested had alkali clearing values above 4.0.

Medium-grain.—Country by country, this class of samples averaged about the same values for both alkali spreading and alkali clearing as did the long-grain samples.

Short-grain.—Short-grain samples generally had higher alkali spreading and alkali clearing than the other two types. The range among the short-grain samples was least of the three types.

Parboiled Milled Rice

Not sufficient parboiled samples were evaluated for alkali spreading and alkali clearing to draw definite conclusions. Those parboiled samples tested seemed comparable to the milled samples.

TABLE 11.—ALKALI SPREADING: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*		*Scores*	*Scores*
"All samples"	53	5.4	2.3–7.0	52	5.3	2.6–7.0	48	6.7	4.0–7.0
U.S.A.	6	5.3	2.3–7.0	5	6.5	5.7–7.0	2	7.0	7.0–7.0
Africa, South									
Argentina				1	4.0		1	7.0	
Australia							1	7.0	
Brazil	2	5.9	5.8–6.0	2	5.5	4.0–7.0	1	7.0	
Burma	4	4.9	4.2–5.8	10	5.0	4.7–5.5			
Ceylon									
Chile									
Colombia	3	6.0	5.7–6.4						
Ecuador	1	4.7		3	5.0	4.8–5.3			
Egypt							1	7.0	
El Salvador									
France							2	7.0	7.0–7.0
Germany, West	2	5.4	5.2–5.7				1	6.8	
Ghana									

Greece	1	7.0	-------	-------	-------	-------	2	7.0	7.0–7.0
Guatemala	-------	-------	-------	-------	-------	-------	-------	-------	-------
India	11	5.3	4.2–6.8	13	4.8	2.6–5.9	5	5.2	4.0–5.7
Indonesia	9	4.9	3.2–7.0	2	5.1	4.8–5.4	-------	-------	-------
Iran	1	5.5	-------	1	4.8	-------	1	6.3	-------
Italy	2	6.4	6.2–6.6	-------	-------	-------	2	7.0	7.0–7.0
Ivory Coast	-------	-------	-------	-------	-------	-------	-------	-------	-------
Japan	-------	-------	-------	3	6.9	6.8–7.0	19	6.9	6.3–7.0
Korea	-------	-------	-------	-------	-------	-------	6	7.0	6.9–7.0
Mexico	5	5.4	4.7–6.8	-------	-------	-------	-------	-------	-------
Nigeria	-------	-------	-------	-------	-------	-------	-------	-------	-------
Pakistan, East	-------	-------	-------	-------	-------	-------	-------	-------	-------
Pakistan, West	3	4.7	4.2–5.7	-------	-------	-------	-------	-------	-------
Peru	1	6.2	-------	-------	-------	-------	-------	-------	-------
Philippines	-------	-------	-------	9	5.1	4.6–5.5	-------	-------	-------
Portugal	-------	-------	-------	2	7.0	7.0–7.0	-------	-------	-------
Spain	-------	-------	-------	-------	-------	-------	2	6.6	6.5–6.8
Thailand	2	6.3	6.0–6.6	1	5.2	-------	-------	-------	-------
Turkey	-------	-------	-------	-------	-------	-------	2	7.0	7.0–7.0

Continued

TABLE 11.—ALKALI SPREADING: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Score	*Scores*		*Score*	*Scores*
"All samples"	7	5. 3	4. 9–6. 0	9	5. 1	4. 4–6. 0
U.S.A	1	5. 6				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	6. 0	6. 0–6. 0
Ghana						

Greece	-	-	-	-	-	-
Guatemala	-	-	-	-	-	-
India	3	5. 4	5. 0–6. 0	5	4. 9	4. 5–5. 7
Indonesia	-	-	-	-	-	-
Iran	-	-	-	-	-	-
Italy	-	-	-	-	-	-
Ivory Coast	-	-	-	-	-	-
Japan	-	-	-	-	-	-
Korea	-	-	-	-	-	-
Mexico	-	-	-	-	-	-
Nigeria	-	-	-	-	-	-
Pakistan, East	1	5. 2	-	2	4. 8	4. 4–5. 2
Pakistan, West	-	-	-	-	-	-
Peru	-	-	-	-	-	-
Philippines	-	-	-	-	-	-
Portugal	-	-	-	-	-	-
Spain	-	-	-	-	-	-
Thailand	2	5. 2	4. 9–5. 6	1	4. 8	-
Turkey	-	-	-	-	-	-

TABLE 12.—ALKALI CLEARING: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*		*Scores*	*Scores*
"All samples"	53	4. 6	1. 3–7. 0	52	4. 7	1. 9–7. 0	48	6. 6	3. 3–7. 0
U.S.A.	6	4. 5	1. 3–7. 0	5	6. 2	4. 9–7. 0	2	6. 9	6. 8–7. 0
Africa, South									
Argentina				1	2. 7		1	7. 0	
Australia							1	7. 0	
Brazil	2	5. 2	5. 0–5. 5	2	4. 8	2. 6–7. 0	1	7. 0	
Burma	4	4. 5	3. 7–5. 6	10	4. 3	2. 6–5. 2			
Ceylon									
Chile									
Colombia	3	5. 0	4. 4–5. 4						
Ecuador	1	3. 4		3	4. 4	4. 2–4. 7			
Egypt							1	7. 0	
El Salvador									
France							2	7. 0	7. 0–7. 0
Germany, West	2	5. 1	5. 0–5. 2				1	6. 5	
Ghana									

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Greece	1	7. 0	----	----	----	----	2	7. 0	7. 0–7. 0
Guatemala	----	----	----	----	----	----	----	----	----
India	11	4. 6	2. 5–6. 7	13	4. 0	1. 9–5. 8	5	4. 9	3. 3–5. 6
Indonesia	9	3. 7	2. 3–4. 9	2	4. 2	3. 6–4. 9	----	----	----
Iran	1	4. 8	----	1	4. 0	----	1	5. 9	----
Italy	2	6. 4	6. 6–6. 2	----	----	----	2	7. 0	7. 0–7. 0
Ivory Coast	----	----	----	----	----	----	----	----	----
Japan	----	----	----	3	6. 9	6. 8–7. 0	19	6. 8	6. 0–7. 0
Korea	----	----	----	----	----	----	6	7. 0	6. 9–7. 0
Mexico	5	4. 7	3. 3–6. 8	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----	----	----	----
Pakistan, East	----	----	----	----	----	----	----	----	----
Pakistan, West	3	3. 6	2. 4–5. 4	----	----	----	----	----	----
Peru	1	5. 5	----	----	----	----	----	----	----
Philippines	----	----	----	9	4. 6	4. 1–5. 2	----	----	----
Portugal	----	----	----	2	7. 0	7. 0–7. 0	----	----	----
Spain	----	----	----	----	----	----	2	6. 5	6. 5–6. 5
Thailand	2	6. 2	5. 9–6. 4	1	4. 3	----	----	----	----
Turkey	----	----	----	----	----	----	2	7. 0	7. 0–7. 0

Continued

TABLE 12.—ALKALI CLEARING: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*
"All samples"	6	4. 8	4. 0–5. 8	9	4. 6	3. 8–6. 0
U.S.A.	1	5. 5				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	6. 0	6. 0–6. 0
Ghana						

Greece	----	----	----	----	----	----
Guatemala	----	----	----	----	----	----
India	3	4. 5	4. 0–5. 2	5	4. 2	3. 8–4. 9
Indonesia	----	----	----	----	----	----
Iran	----	----	----	----	----	----
Italy	----	----	----	----	----	----
Ivory Coast	----	----	----	----	----	----
Japan	----	----	----	----	----	----
Korea	----	----	----	----	----	----
Mexico	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----
Pakistan, East	1	4. 6	----	2	4. 2	3. 8–4. 6
Pakistan, West	----	----	----	----	----	----
Peru	----	----	----	----	----	----
Philippines	----	----	----	----	----	----
Portugal	----	----	----	----	----	----
Spain	----	----	----	----	----	----
Thailand	2	5. 4	5. 1–5. 8	1	4. 0	----
Turkey	----	----	----	----	----	----

Chemical Determinations

Lipid Content

A high percentage of the lipid content of the rice kernel occurs in the true bran (pericarp) and embryo (*33*).

Autrey and others (*3*) demonstrated, in 322 tests of Zenith and Rexark rices, that the amount of fat extracted from whole milled rice was in linear relationship to the amount of bran removed up to about 6 percent of the original rice. It was further shown that, for a given variety, the relationship between the percentage of bran removed and the percentage of fat remaining on the milled rice is constant from year to year. Those studies indicate that reliable and consistent results can be obtained by using the fats extractable from the surface of the whole-milled rice as a measure of the amount of inner bran (the aleurone layer) remaining on the milled rice.

Since the outer layers of rice kernels may be removed by milling, the greater the milling the less will be the lipid content, particularly the so-called surface lipids. For this reason, the determination of the surface lipids may be indicative of the degree of milling.

For the samples analyzed in this study, it was found that surface lipids averaged about 60 percent of the total lipid content. Rices with a high percentage of surface lipids had high total lipid contents.

Surface Lipids

Table 13 depicts surface lipid data for rices by individual countries, as well as the mean and range for "all samples," according to rice types.

Milled Rice

In general, long-grain milled rices had the lowest surface lipid content, medium-grains were intermediate, and short-grain samples had the highest amounts of surface lipids.

Samples from West Germany, Greece, and Portugal had much lower average surface lipid content than did "all samples" or U.S. samples. Conversely, Japanese samples were much higher. Curiously enough, long- and medium-grain samples from Indonesia, which probably included indigenous hand-pounded samples, were very high, but the reverse was true for the short-grain samples of that country, which included imported samples.

As has been found by other research workers in this field, these studies showed a high positive correlation (table 27) between surface lipids and total lipids for long-, medium-, and short-grain categories as well as for total samples (combined long, medium, and short).

Color lightness values increased as surface lipids diminished, in long-, medium-, and short-grain types, with the effect increasing as grain length became shorter.

There were strong indications that as surface lipids decreased in long-grain rices, there was improvement in cooking quality appearance scores. The opposite trend may be true for short-grain rices, but more research is needed to determine to what extent.

Surface lipids also appeared to affect cooking quality cohesiveness. For long-grain rices, stickiness during cooking seemed to decrease as surface lipid content decreased. However, the opposite may be true for short-grain rices. Knowledge on these phenomena is vital to a better understanding of cooking characteristics; more research is necessary on these points.

Long-grain.—Samples from Ivory Coast, Indonesia, and Peru had very high surface lipid values. On the other hand, samples from South Africa, France, West Germany, Greece, and Portugal had the lowest. One sample from India had the lowest value of any sample studied. Such low values would indicate a higher degree of milling than average, and were lower than U.S. long-grain (which averaged about the same as "all samples" for long-grain).

Medium-grain.—High lipid content was found among samples from Ceylon, India, Indonesia, Peru, and the Philippines. Those with unusually low lipid content were from Burma, Colombia, West Germany, and Greece.

Short-grain.—U.S. rices had less than the "all samples" average for this class; samples from South Africa, Egypt, Argentina, Brazil, France, West Germany, Greece, Indonesia, and Portugal had much lower lipid content than did "all samples" averages. Italy and Japan, averaging 0.51 and 0.52 percent, respectively, had the highest amounts of surface lipids.

Parboiled Milled Rice

Samples from East Pakistan, Burma, and Thailand had high amounts of surface lipids. The long- and medium-grain parboiled milled samples averaged somewhat higher than the milled rices for surface lipids.

For the samples studied in this project, parboiled milled rices had slightly higher amounts of surface lipids than did the milled samples, principally because the beginning range was two to three times higher than that for milled samples.

TABLE 13.—SURFACE LIPIDS: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	156	0.349	0.092–0.827	147	0.392	0.067–0.842	129	0.404	0.050–0.791
U.S.A	6	.346	.283–.427	5	.366	.316–.395	2	.350	.333–.368
Africa, South	2	.278	.215–.340	1	.470		2	.265	.210–.320
Argentina				4	.345	.330–.390	4	.272	.240–.350
Australia							1	.340	
Brazil	7	.349	.271–.443	5	.330	.201–.495	3	.227	.201–.260
Burma	8	.417	.331–.503	35	.277	.067–.566			
Ceylon				7	.547	.160–.842	3	.436	.184–.791
Chile									
Colombia	4	.333	.167–.647	1	263				
Ecuador	2	.320	.268–.372	4	.340	.305–.395			
Egypt							5	.240	.090–.620
El Salvador									
France	4	.240	.180–.300				2	.265	.260–.270
Germany, West	5	.286	.190–.400	4	.258	.150–.320	3	.197	.180–.230
Ghana									

Greece	6	.228	.180- .290	2	.155	.090- .220	8	.181	.090- .240
Guatemala	2	.344	.319- .370	---	---	---	---	---	---
India	19	.313	.114- .607	20	.518	.125- .836	8	.345	.235- .543
Indonesia	18	.597	.336- .827	8	.502	.290- .730	4	.192	.050- .430
Iran	9	.319	.269- .356	5	.319	.258- .390	1	.400	---
Italy	6	.400	.370- .430	---	---	---	3	.513	.490- .550
Ivory Coast	1	.674	---	---	---	---	1	.480	---
Japan	6	.360	.350- .370	18	.417	.280- .570	60	.521	.300- .670
Korea	---	---	---	---	---	---	10	.345	.200- .490
Mexico	8	.339	.258- .429	---	---	---	---	---	---
Nigeria	---	---	---	---	---	---	---	---	---
Pakistan, East	---	---	---	---	---	---	---	---	---
Pakistan, West	11	.398	.253- .489	1	.418	---	---	---	---
Peru	6	.665	.560- .820	4	.498	.420- .580	---	---	---
Philippines	---	---	---	11	.484	.405- .613	---	---	---
Portugal	1	.180	---	3	.307	.190- .440	1	.270	---
Spain	---	---	---	---	---	---	5	.296	.200- .510
Thailand	24	.301	.092- .628	6	.394	.140- .651	---	---	---
Turkey	1	.330	---	3	.447	.360- .500	3	.443	.330- .540

Continued

TABLE 13.—SURFACE LIPIDS: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	38	0. 450	0. 220–0. 768	26	0. 448	0. 169–0. 828
U.S.A.	1	. 197				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	. 389	3. 72 –4. 12	8	. 551	. 179– . 828
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	. 285	. 230– . 340
Ghana						

Greece						
Guatemala						
India	6	.319	.240- .442	7	.278	.208- .449
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	6	.688	.633- .768	6	.525	.297- .755
Pakistan, West						
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	.425	.220- .628	3	.527	.500- .544
Turkey						

Total Lipids

As stated previously in this report, these studies conclusively showed that as surface lipids increased, there was a related increase of total lipids. On an average, surface lipids were about 60 percent of the total lipid content.

Although there was a wide range of variation in individual determinations in each category—long-, medium-, and short-grain types of both milled and parboiled milled rices—the mean values for "all samples" were almost identical, as shown in table 14.

Milled Rice

In agreement with the findings of other researchers, this study showed that as total lipids increased, the color decreased (table 27). This darkening may be due to the lipids becoming oxidized (rancid), or undergoing decomposition, or reacting with other constituents.

Long-grain.—Rices from Indonesia, Italy, and Peru were particularly high in total lipids; U.S. samples were below the "all samples" average; and samples obtained in Ecuador and Portugal were lowest, averaging about half the "all samples" value.

Medium-grain.—Of all categories studied, the medium-grain rices exhibited the widest range in total lipid content, with the lowest sample coming from Burma and the highest from India. The samples from India had, by far, the widest range of all countries.

Short-grain.—Samples from Egypt were the lowest and highest in total lipids of the short-grain rices considered.

Parboiled Milled Rices

U.S. rice had the lowest total lipid and Ghana the highest of the parboiled long-grain rices. Rice from Burma averaged the highest total lipid content of all parboiled rices considered.

Protein (Nitrogen)

Protein content of milled rices may be influenced by the types and amounts of fertilizers applied, by climatic and environmental factors, by degree of maturity, by varietal characteristics, and by the degree of milling (*33*, *43*). Little information was available on the foreign samples used in the present study concerning these background cultural factors. Therefore, the interpretation of the analytical data on protein content, summarized in table 15, may not be as meaningful as desired.

The quantity and kind of proteins are important factors in the nutritional value of rice. Total protein is important, but more and more consideration is being given to the kinds of proteins necessary for health and well-being. Studies of both foreign and domestic rices should be extended to characterize the proteins inherent in the principal varieties of commerce, as guidelines toward production and marketing of more desirable rices.

Ranges of protein content in the long-, medium-, and short-grain categories for milled rices, under consideration in this research project, were not greatly different, one from another, as shown in table 15.

Average and maximum and minimum protein values exhibited a general downward trend from the long- to the short-grain rices, but had considerable range within each grain type. These differences in protein content between grain types may have been affected by one or more of the factors mentioned above. Type for type, the parboiled samples had lower average protein values than the raw milled samples.

Milled Rice

For the longer types of rices, there was some indication that protein content is inversely related to surface lipids (table 27). Also, these studies further confirmed other workers' findings that protein content increased as grain length increased, particularly in the long-grain types (*32*).

As protein content increased, water uptake at both 77° C. and 82° C. decreased, although this behavior was not consistent in all grain lengths. These findings are consistent with other research (*28*) in which protein distribution within rice kernels was demonstrated histochemically for several domestic varieties.

Good evidence was obtained that the higher the protein content the less will be the cohesiveness after cooking. This is in keeping with the fact that the short-grain rices, usually more sticky when cooked than medium- and long-grain rices, average a lower percentage of protein than do the longer grain types. Research should be undertaken to determine which kinds of protein or protein combinations exert the greatest effect on the "stickiness" properties.

Long-grain.—Samples from three countries—Colombia, Iran, and Italy—had very high average protein values (above 9 percent). Iran samples had the highest average value and the smallest range of values. U.S. samples averaged less than that for the whole group. Samples from Indonesia not only averaged the least, but one of the samples was the lowest of any long-grain rices tested.

Medium-grain.—Samples from Argentina, Brazil, Ecuador, and Peru had average protein content exceeding 8.5 percent. With the exception of the single sample from Colombia, the U.S. medium-grain rices averaged lowest of all the countries. India samples had by far the greatest range of values; one of these samples contained the highest amount of protein (10.18 percent) of any sample—milled or parboiled—analyzed in this study.

Short-grain.—U.S. samples averaged lowest of those from any country; Iran samples again had a very high value, exceeded only by those from Ceylon and Spain.

Parboiled Milled Rice

Parboiled rices, type for type, averaged slightly less protein content, but had a more narrow range of values, than the raw milled samples. For long-grain parboiled rices, the lowest and highest protein percentages were found in the Thailand samples. The highest Thailand sample barely exceeded samples from the United States, Nigeria, and India.

TABLE 14.—TOTAL LIPIDS: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	89	0.66	0.19–1.82	102	0.64	0.16–2.73	50	0.66	0.30–1.52
U.S.A	6	.51	.35– .71	5	.52	.45– .57	2	.55	.53– .57
Africa, South	---	---	---	1	.96	---	2	.65	.55– .74
Argentina	---	---	---	1	.88	---	1	.66	---
Australia	---	---	---	---	---	---	1	.66	---
Brazil	5	.53	.40– .67	3	.39	.32– .44	3	.40	.37– .43
Burma	8	.67	.50– .80	35	.49	.16–1.00	---	---	---
Ceylon	---	---	---	---	---	---	---	---	---
Chile	---	---	---	---	---	---	---	---	---
Colombia	4	.60	.36–1.08	1	.37	---	---	---	---
Ecuador	1	.39	---	3	.50	.42– .54	---	---	---
Egypt	---	---	---	---	---	---	5	.61	.30–1.52
El Salvador	---	---	---	---	---	---	---	---	---
France	2	.46	.46– .47	---	---	---	1	.56	---
Germany, West	5	.49	.37– .59	4	.45	.32– .59	3	.37	.36– .38
Ghana	---	---	---	---	---	---	---	---	---

Greece	1	.52	-----	1	.53	-----	-----	-----	-----
Guatemala	-----	-----	-----	-----	-----	-----	-----	-----	-----
India	15	.52	.26– .99	18	.92	.27–2.73	7	.66	.38– .98
Indonesia	11	1.29	.55–1.82	5	.76	.52–1.02	1	.20	-----
Iran	3	.65	.56– .73	2	.70	.47– .94	-----	-----	-----
Italy	2	.93	.91– .95	-----	-----	-----	1	1.21	-----
Ivory Coast	-----	-----	-----	-----	-----	-----	1	.87	-----
Japan	2	.54	.50– .57	5	.67	.45– .88	12	.81	.50–1.07
Korea	-----	-----	-----	-----	-----	-----	4	.77	.65– .87
Mexico	8	.46	.34– .58	-----	-----	-----	-----	-----	-----
Nigeria	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, East	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, West	4	.72	.48– .88	-----	-----	-----	-----	-----	-----
Peru	2	1.06	.91–1.21	-----	-----	-----	-----	-----	-----
Philippines	-----	-----	-----	9	.77	.69–1.09	-----	-----	-----
Portugal	1	.36	-----	3	.56	.38– .83	1	.55	-----
Spain	-----	-----	-----	-----	-----	-----	2	.48	.42– .53
Thailand	8	.59	.19–1.32	3	.84	.53–1.40	-----	-----	-----
Turkey	1	.55	-----	3	.76	.60– .84	3	.76	.57– .94

Continued

TABLE 14.—TOTAL LIPIDS: *Number of samples, mean, and range of values for each country and for "all samples"*—Con

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
All "samples"	15	0. 60	0. 41–0. 90	20	0. 64	0. 28–1. 29
U.S.A	1	0. 27				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	. 53	. 50– . 56	8	. 76	. 29–1. 29
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	. 42	. 33– . 51
Ghana	1	1. 14				

Greece						
Guatemala						
India	3	.51	.41– .68	6	.48	.28– .76
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	2	.86	.82– .90	2	.73	.43–1.03
Pakistan, West	2	.83	.78– .88			
Peru						
Philippines						
Portugal						
Spain						
Thailand	5	.57	.42– .86	2	.74	.70– .79
Turkey						

TABLE 15.—PROTEIN: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	156	8.32	6.40–9.99	147	7.78	6.20–10.18	129	7.31	5.63–9.40
U.S.A.	6	8.17	7.02–9.34	5	6.98	6.21– 7.94	2	5.90	5.63–6.17
Africa, South	2	8.67	8.38–8.96	1	7.62		2	7.08	6.84–7.32
Argentina				4	8.69	8–57– 8.81	4	7.66	7.56–7.73
Australia							1	6.31	
Brazil	7	8.96	7.79–9.85	5	8.73	7.02– 9.94	3	7.88	7.62–8.33
Burma	8	8.01	7.06–8.60	35	7.70	6.20– 8.62			
Ceylon				7	8.39	7.08– 9.08	3	8.57	7.39–9.40
Chile									
Colombia	4	9.40	8.36–9.94	1	6.07				
Ecuador	2	8.09	7.40–8.78	4	8.54	7.59– 9.45			
Egypt							5	6.63	5.71–7.20
El Salvador									
France	4	8.91	7.73–9.34				2	6.99	6.78–7.20
Germany, West	5	8.75	8.33–9.52	4	7.56	7.32– 7.79	3	7.34	6.72–8.33
Ghana									

Greece	6	8. 29	8. 15–8. 51	2	7. 14	6. 96– 7. 32	8	6. 95	6. 37–7. 91
Guatemala	2	7. 78	7. 55–8. 00	------	------	------	------	------	------
India	19	7. 95	6. 84–9. 40	20	7. 56	6. 60–10. 18	8	7. [illegible]	5. 80–9. 08
Indonesia	18	7. 65	6. 40–9. 27	8	8. 00	7. 56– 8. 65	4	7. 28	6. 90–7. 68
Iran	9	9. 82	9. 76–9. 99	5	8. 19	7. 79– 8. 37	1	8. 15	------
Italy	6	9. 26	8. 98–9. 58	------	------	------	3	7. 28	7. 26–7. 32
Ivory Coast	1	7. 99	------	------	------	------	1	7. 08	------
Japan	6	7. 72	7. 38–8. 03	18	7. 43	6. 78– 8. 03	60	7. 32	6. 19–8. 98
Korea	------	------	------	------	------	------	10	7. 09	6. 13–7. 68
Mexico	8	8. 95	8. 67–9. 48	------	------	------	------	------	------
Nigeria	------	------	------	------	------	------	------	------	------
Pakistan, East	------	------	------	------	------	------	------	------	------
Pakistan, West	11	7. 70	6. 97–8. 34	1	7. 11	------	------	------	------
Peru	6	8. 12	7. 56–8. 69	4	8. 76	7. 44– 9. 58	------	------	------
Philippines	------	------	------	11	7. 68	7. 11– 8. 45	------	------	------
Portugal	1	8. 45	------	3	7. 54	7. 32– 7. 68	1	6. 31	------
Spain	------	------	------	------	------	------	5	8. 27	7. 79–9. 10
Thailand	24	8. 24	7. 29–9. 55	6	7. 88	7. 10– 8. 40	------	------	------
Turkey	1	8. 69	------	3	7. 64	7. 26– 7. 97	3	7. 58	7. 20–8. 15

Continued

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TABLE 15.—PROTEIN: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	38	7.73	6.53–8.86	26	7.56	6.36–10.09
U.S.A	1	8.61				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	7.17	7.16–7.19	8	7.46	7.15–7.58
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	7.32	7.26–7.38
Ghana	1	7.44				

Greece						
Guatemala						
India	6	7. 90	7. 12–8. 72	7	7. 15	6. 64– 7. 61
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria	1	8. 61				
Pakistan, East	6	7. 63	6. 69–8. 45	6	8. 20	6. 36–10. 09
Pakistan, West	6	7. 45	7. 28–7. 61			
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	7. 83	6. 53–8. 86	3	6. 99	6. 55– 7. 92
Turkey						

Moisture

The moisture content of rice is an important factor in determining its keeping qualities. During storage, high-moisture samples change quality characteristics faster than those with lower moisture content. Moisture content is a transitory factor, affected by maturity, drying, and storage environment. Commonly accepted moisture contents for safe storage are 13 percent for less than 6 months' storage, and 12 percent for long-time storage (*10*).

In the United States, rice with more than 15 percent moisture is classed as sample grade. Among the foreign rices examined, the moisture content ranged from about 9.5 percent to 16 percent (table 16). Some samples received from Brazil, Burma, Greece, Indonesia, Japan, Korea, and Thailand contained in excess of 15 percent moisture. The ranges of moisture percentages found within the different kernel type categories were not widely different in these foreign rices. High- and low-moisture values were fairly well randomized throughout the various countries, irrespective of widely ranging climatic conditions, handling methods, and other factors.

Milled rices had a somewhat wider range in moisture values than did the parboiled milled samples.

Milled Rice

Average moisture values for the three grain lengths did not show any wide difference, and no consistent trend was found among the three types.

India samples had the lowest percentage moisture in each of three grain types—long-, medium-, and short-grain rices. Furthermore, the sample with the lowest moisture in each category was from India.

Long-grain.—Indonesia had the highest moisture sample and the highest average for any country in this group. The Thailand samples were next highest in moisture content. U.S. long-grain rices averaged somewhat below the group average.

Medium-grain.—The Burma samples had the highest moisture content. U.S. rices averaged next to those from India in being the lowest in moisture.

Short-grain.—Rices from Korea, Japan, and Greece ranked highest in moisture. Rices from India had the lowest values, followed rather closely by rices from Egypt and Spain.

Parboiled Milled Rice

Here again it was noted that the India samples were lowest in average moisture content and had the lowest individual sample moisture of any examined in this project. As noted previously, the moisture range was less for parboiled samples than for the raw milled ones.

Crude Fiber

Most of the crude fiber of rough rice is in the bran and outer layers. Although there may be varietal differences, the fiber content of milled rice is largely a function of the degree of milling. It was not surprising, therefore, that the fiber content exhibited random variation among the samples examined in this investigation (table 17). Although the percentage of fiber in these samples ranged from 0.18 to 1.28 percent, the average values of the different categories were not much different from each other (table 17). The sample with 1.28 percent crude fiber also was high in protein (10.18 percent) and in ash (1.62 percent), which indicated it was only very lightly milled. For these reasons, this study did not afford much basis for relating fiber content with cooking and processing qualities. Research on pure varieties with known histories, with controlled degrees of milling, would be the only sound approach to establishing such relationships.

Milled Rice

For the milled samples, trends for crude fiber content were consistently downward from long- to medium- to short-grains.

Long-grain.—Samples from Indonesia and West Pakistan had much higher percentages of crude fiber than others in this class, and evidently were undermilled. This was consistent with the findings that these samples also had high surface lipid content, indicating less milling. On the other hand, samples from Germany, Japan, and Mexico averaged lowest in crude fiber, which was consistent with their having low amounts of surface lipids. U.S. samples were about average.

Medium-grain.—High crude fiber values for India and Thailand are probably not due to undermilling. Those from India had the greatest variability of any country for all rice types. Samples from Japan had the lowest crude fiber content, which is consistent with its high milling practice. Medium-grain rices from the U.S., with least range of values, were somewhat below average in fiber, which is consistent with higher degree of milling than most foreign samples.

Short-grain.—Samples from Egypt varied most; those from India had least variation.

Parboiled Milled Rice

The range of crude fiber values was smaller for the parboiled milled rices than for the milled-rice samples.

TABLE 16.—MOISTURE: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	156	13.58	9.54–16.01	146	13.67	9.52–15.46	127	13.76	10.32–15.87
U.S.A.	6	13.10	12.26–14.08	5	12.47	12.14–12.68			
Africa, South									
Argentina									
Australia									
Brazil	7	13.75	12.16–14.94	5	13.88	12.18–15.15			
Burma	8	13.96	13.28–15.18	35	14.59	13.22–15.46			
Ceylon				6	13.88	13.48–14.74			
Chile									
Colombia									
Ecuador									
Egypt									
El Salvador									
France							5	12.51	11.70–13.50
Germany, West	5	12.68	12.20–13.28						
Ghana									

Greece	6	13.02	11.97–13.72				8	14.11	12.05–15.87
Guatemala									
India	19	11.84	9.54–13.28	20	12.27	9.52–14.18	8	12.05	10.32–13.59
Indonesia	18	15.01	14.39–16.01	8	13.84	13.41–14.30			
Iran	9	11.87	11.22–12.54						
Italy	6	13.25	12.90–13.74						
Ivory Coast									
Japan	6	13.20	12.80–13.69	18	13.97	12.96–14.84	60	14.22	12.84–15.74
Korea							10	14.72	14.34–15.29
Mexico	8	12.72	10.86–14.58						
Nigeria									
Pakistan, East									
Pakistan, West	11	13.22	12.69–13.66						
Peru	6	13.94	13.52–14.37						
Philippines				11	13.42	12.69–14.30			
Portugal									
Spain							5	12.88	12.10–13.82
Thailand	24	14.31	12.89–15.14	6	14.14	13.84–14.66			
Turkey									

Continued

TABLE 16.—MOISTURE: *Number of samples, mean, and range of values for each country and for "all samples"*—Con.

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	38	13.32	10.81–15.20	26	13.41	10.51–15.06
U.S.A.						
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon				8	14.60	14.21–15.06
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West						
Ghana						

Greece						
Guatemala						
India	6	11. 72	10. 81. –13. 44	7	12. 08	10. 51–13. 30
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	6	13. 39	13. 07–13. 74	6	13. 37	12. 93–13. 76
Pakistan, West	6	13. 05	12. 52–13. 81			
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	14. 08	12. 93–15. 20			
Turkey						

TABLE 17.—CRUDE FIBER: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	88	0. 35	0. 18–0. 68	103	0. 32	0. 22–1. 28	49	0. 29	0. 19–0. 68
U.S.A.	6	. 332	. 28– . 40	5	. 286	. 26– . 30	-----	-----	-----
Africa, South	-----	-----	-----	-----	-----	-----	-----	-----	-----
Argentina	-----	-----	-----	-----	-----	-----	-----	-----	-----
Australia	-----	-----	-----	-----	-----	-----	-----	-----	-----
Brazil	4	. 350	. 24– . 48	3	. 287	. 26– . 32	-----	-----	-----
Burma	8	. 316	. 23– . 48	35	. 313	. 22– . 45	-----	-----	-----
Ceylon	-----	-----	-----	-----	-----	-----	-----	-----	-----
Chile	-----	-----	-----	-----	-----	-----	-----	-----	-----
Colombia	-----	-----	-----	-----	-----	-----	-----	-----	-----
Ecuador	-----	-----	-----	-----	-----	-----	-----	-----	-----
Egypt	-----	-----	-----	-----	-----	-----	-----	-----	-----
El Salvador	-----	-----	-----	-----	-----	-----	5	. 314	. 19– . 68
France	-----	-----	-----	-----	-----	-----	-----	-----	-----
Germany, West	5	. 278	. 24– . 31	-----	-----	-----	-----	-----	-----
Ghana	-----	-----	-----	-----	-----	-----	-----	-----	-----

Greece	1	.340	---	---	---	---	---	---	---
Guatemala	---	---	---	---	---	---	---	---	---
India	15	.307	.24–.41	18	.396	.25–1.28	7	.306	.28–.32
Indonesia	11	.482	.25–.68	5	.326	.24–.52	---	---	---
Iran	3	.407	.34–.46	---	---	---	---	---	---
Italy	2	.360	---	---	---	---	---	---	---
Ivory Coast	---	---	---	---	---	---	---	---	---
Japan	2	.290	.24–.34	5	.256	.22–.33	12	.282	.22–.34
Korea	---	---	---	---	---	---	3	.280	.23–.34
Mexico	8	.236	.18–.31	---	---	---	---	---	---
Nigeria	---	---	---	---	---	---	---	---	---
Pakistan, East	---	---	---	---	---	---	---	---	---
Pakistan, West	4	.548	.46–.60	---	---	---	---	---	---
Peru	2	.395	.36–.43	---	---	---	---	---	---
Philippines	---	---	---	9	.290	.26–.32	---	---	---
Portugal	---	---	---	---	---	---	---	---	---
Spain	---	---	---	---	---	---	2	.260	.23–.29
Thailand	8	.346	.25–.50	4	.433	.33–.50	---	---	---
Turkey	---	---	---	---	---	---	---	---	---

Continued

TABLE 17.—CRUDE FIBER: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	17	0. 37	0. 26–0. 62	20	0. 35	0. 23–0. 50
U.S.A.						
Africa, South						
Argentina						
Australia						
Brazil						
Burma				8	. 369	. 28– . 42
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West						
Ghana						

Greece	---	---	---	---	---	---
Guatemala	---	---	---	---	---	---
India	3	.323	.30–.36	6	.303	.23–.34
Indonesia	---	---	---	---	---	---
Iran	---	---	---	---	---	---
Italy	---	---	---	---	---	---
Ivory Coast	---	---	---	---	---	---
Japan	---	---	---	---	---	---
Korea	---	---	---	---	---	---
Mexico	---	---	---	---	---	---
Nigeria	---	---	---	---	---	---
Pakistan, East	2	.440	.42–.46	2	.470	.44–.50
Pakistan, West	2	.590	.56–.62	---	---	---
Peru	---	---	---	---	---	---
Philippines	---	---	---	---	---	---
Portugal	---	---	---	---	---	---
Spain	---	---	---	---	---	---
Thailand	5	.330	.26–.41	---	---	---
Turkey	---	---	---	---	---	---

Ash

Ash content of rice may be affected by several factors. It has been reported (*33*) that the amount of ash in rice is significantly influenced by cultural environment and less significantly by variety of the rice. In other words, variation in percentage of ash may reflect variation in inorganic constituents of the soil, fertilizer, and water in which the rice was grown.

Of all the parts of the rice kernel, the principal source of ash is from the bran layer, which may have an ash content of up to about 5 percent (*33*). These same investigators reported that the endosperm of rice may contain up to 0.61 percent ash. It may be assumed, therefore, that samples with high ash values are either not well-milled or are admixed with foreign matter of high mineral content.

Ash percentages of all samples examined ranged from 0.26 to 1.95. The highest average value for ash (1.49 percent) was found in the long-grain samples obtained from West Germany (table 18). However, this finding was not meaningful because the Germany samples represented rices from several countries.

The highest amount of ash in a medium-grain sample was obtained in India.

Although the proportion of ash to crude fiber showed considerable variation among the wide range of samples examined, it was interesting to note that the ash average for the different categories was approximately two times the average of crude fiber:

Rice type	*Milled* *Ash/fiber*	*Parboiled* *Ash/fiber*
Long-grain	2.00	2.03
Medium-grain	2.04	2.23
Short-grain	2.09	----

Milled Rice

The milled samples averaged about 0.65 percent ash. The U.S. rices examined (long- and medium-grain) averaged about two-thirds that for all rices, which further substantiates the belief that U.S. rices have a comparably higher degree of milling and perhaps more efficient handling and processing that minimizes mineral contamination.

Long-grain.—Greatest amounts of ash were found in samples from West Germany, Indonesia, and Peru. U.S. long-grain rices had the lowest percentage of ash. Other low-ash samples came from Iran, Mexico, and Thailand.

Medium-grain.—Again, the U.S. samples averaged the lowest in ash content and had the least range of values. Others with low ash percentages were from Brazil, Burma, and Japan. The samples from India had by far the highest amount of ash.

Short-grain.—In this category, ash content was determined for only five countries. These country averages (except Egypt's) were exceedingly close together, with a range of only 0.05 percent.

Parboiled Milled Rice

Ash content of parboiled milled samples was slightly higher than for the raw milled rices. Variation in ash content for both long- and medium-grains was substantially less than for the raw milled rices.

TABLE 18.—ASH: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	88	0. 69	0. 26–1. 95	104	0. 64	0. 34–1. 90	47	0. 61	0. 36–1. 19
U.S.A.	6	. 40	. 36– . 48	5	. 46	. 42– . 49			
Africa, South									
Argentina									
Australia									
Brazil	4	. 55	. 30– . 72	3	. 52	. 39– . 63			
Burma	8	. 60	. 54– . 71	35	. 51	. 34– . 72			
Ceylon									
Chile				2	. 64	. 51– . 76			
Colombia									
Ecuador									
Egypt							5	. 63	. 36–1. 19
El Salvador									
France									
Germany, West	5	1. 49	. 56–1. 95						
Ghana									

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Greece	1	.59	----	----	----	----	----	----	----
Guatemala	----	----	----	----	----	----	----	----	----
India	15	.65	.44–1.14	18	.90	.56–1.90	7	.63	.46– .98
Indonesia	11	1.02	.55–1.46	5	.62	.34–1.02	----	----	----
Iran	3	.49	.45– .52	----	----	----	----	----	----
Italy	2	.74	.72– .76	----	----	----	----	----	----
Ivory Coast	----	----	----	----	----	----	----	----	----
Japan	2	.53	.52– .54	5	.53	.48– .60	12	.66	.61– .74
Korea	----	----	----	----	----	----	3	.61	.55– .64
Mexico	8	.49	.36– .61	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----	----	----	----
Pakistan, East	----	----	----	----	----	----	----	----	----
Pakistan, West	4	.62	.53– .67	----	----	----	----	----	----
Peru	2	.96	.87–1.04	----	----	----	----	----	----
Philippines	----	----	----	9	.62	.55– .74	----	----	----
Portugal	----	----	----	----	----	----	----	----	----
Spain	----	----	----	----	----	----	2	.61	.52– .70
Thailand	8	.49	.26– .91	4	.78	.51– .93	----	----	----
Turkey	----	----	----	----	----	----	----	----	----

Continued

TABLE 18.—ASH: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	17	0. 75	0. 38–1. 31	20	0. 78	0. 63–1. 06
U.S.A						
Africa, South						
Argentina						
Australia						
Brazil						
Burma				8	. 78	. 63– . 90
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West						
Ghana						

Greece						
Guatemala						
India	3	.67	.64–.70	6	.72	.63–.77
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	2	1.03		2	.98	.89–1.06
Pakistan, West	2	.72	.54–.90			
Peru						
Philippines						
Portugal						
Spain						
Thailand	5	.60	.38–.70			
Turkey						

Starch Content

Starch makes up nearly 90 percent of the total dry matter of milled rice, and consists of two molecular types: Amylose, whose molecules are linear chains of glucose units; and amylopectin, in which the molecular chain is highly branched. Many researchers have made various claims as to the roles played by each of these molecular types of starch—how they may affect cohesiveness and texture after cooking, tendency of the kernels to break, and various processing characteristics. Many of these claims are still in the speculative stage, however, and it is believed this study may clarify some of these points.

Amylose Starch

Although the reaction of rice to heating (as in cooking) may be tempered by factors such as ripeness when harvested, milling, conditions and length of storage, and heating conditions (*11*), it is largely dependent on compositional factors, of which starch is the major component. The relation to cooking quality of starch and its fractions—amylose and amylopectin—has been a frequent subject for investigation.

There has been a growing acceptance that the percentage of amylose plays an important part in determining the cooking and processing qualities of rice. U.S. long-grain rices usually cook to a light, fluffy consistency, whereas cooked short-grain rices commonly tend to be pasty and cohesive (*5*). Williams and others (*45*) found that, as a general rule in U.S. rice, long-grain varieties had a higher amylose content than did medium- and short-grain varieties. Toro and Century Patna were exceptions, however. Those investigators also observed that cooked samples of Toro differed in moistness from those of other long-grain varieties, such as Rexoro and Bluebonnet.

In this study on foreign rices, the mean amylose content for long- and medium-grain rices was almost identical, and the short-grain varieties had about 4 percent less amylose than either of the other grain types (table 19). Fukuya, according to Nagai (*37*), assumed from his studies that the amylose content of the starch from japonica varieties was less than that from indica varieties. Results of the present study substantiate his view. Many of the long-grain varieties grown in the Temperate Zone are progeny of hybrids of japonica and indica parents. Varieties of this type, even though the grain is long, often are low in amylose content. Long-grain varieties from France, Greece, Italy, and Portugal are of this type, and all are low in amylose content. On the other hand, many indica varieties from southeast Asia are medium- and short-grain types when classified according to the criteria used in this study. Thus, when samples from all sources are averaged, the mean and range of amylose content for the three grain-length classes are similar. The results suggest that amylose is not the only component of rice contributing to its cooking and processing behavior. It is possible, as Fukuya (*37*) suggests, that the length of the terminal chain of the amylopectin may affect cooking behavior. It also may be true that the amount and composition of the protein fraction may have a major effect on cooking quality.

Milled Rice

Table 19 reveals some interesting information about amylose content of rices from different countries. Of interest are the high amylose content of the indica types of rices from Ceylon, India, Iran, East and West Pakistan, and Thailand, and the very low amylose values found in japonica type varieties from Argentina, Brazil, Colombia, France, Germany, Indonesia, Italy, Japan, and Portugal. Some of the imported samples collected in Japan had high amylose content.

For long-grain rice, increase in amylose content seemed to be accompanied by darkening in color of the raw milled kernels (table 27).

As amylose content increased, there was a significant decrease in alkali spreading, alkali clearing, and water uptake (greater decrease at 77° C. than at 82° C.).

There was some indication, but not to a highly significant degree, that as amylose increased, there was a decrease in cohesiveness when cooked. Evidence also was found, in the medium-grain rices, that increasing amylose content exerted an adverse effect on flavor and appearance after cooking.

Long- and medium-grain rices contained about the same amounts of amylose, although the parboiled samples were somewhat higher in amylose than the raw milled ones.

Long-grain.—Samples from Greece, Italy, Portugal, and Turkey averaged lowest in amylose. On the other hand, highest amylose was found, on the average, in those from India, Japan, West Pakistan, and Thailand. U.S. rices were somewhat lower than the average for the foreign samples.

Medium-grain.—U.S. rices were almost the lowest in amylose content of all the samples, with only those from Argentina and Colombia being lower. Samples from Japan and Burma had widest ranges.

Short-grain.—Except for the samples from Ceylon and India, the country averages for short-grain rices were rather close together. Short-grain samples averaged lower than the long- and medium-grain samples, which averaged rather close together.

Parboiled Milled Rice

Parboiled rices averaged slightly higher amylose content, and had somewhat less range in variation, than the raw milled rices. Both long-grain and medium-grain samples from East Pakistan and India averaged higher than the other countries in percentage of amylose starch.

Amylopectin Starch

Since amylopectin is complementary to amylose in the makeup of rice starch—which varies little in total percentage (about 90 percent) of the dry matter of milled rice—it is evident that its ranges of value of amylopectin among the different categories and its relationship to cooking and processing quality follow an inverse trend to those of amylose.

Amylopectin content increased, for both milled and parboiled rices, as grain length decreased. Milled rices, type for type, had somewhat more amylopectin than the parboiled rices.

Table 20 gives detailed information concerning amylopectin content of the milled and parboiled samples studied.

Milled Rice

From these studies, it would seem worthwhile to investigate further the possible relationship between amylopectin content and percentage of broken kernels, and between amylopectin and color.

As expected from the findings under studies of amylose, it was found that increase in amylopectin content accompanied increase in alkali spreading and clearing and in water uptake (less at 82° C.). (See table 27.)

Some evidence was obtained to indicate that as amylopectin increased, the cohesiveness (stickiness) increased. Also, it was indicated that with increasing amylopectin, the cooked grains became softer and mushier. However, increasing amylopectin seemed to be associated with improved flavor after cooking. These findings are consistent with the fact that short-grain rices, inherently more sticky than other types after cooking, have more amylopectin than long- and medium-grain rices.

Long-grain.—Some samples from the United States, Burma, West Germany, Greece, and Italy contained above 70 percent amylopectin. Long-grain rices from India, Iran, and West Pakistan, with averages less than 60 percent, had the lowest amounts of amylopectin.

Medium-grain.—Here again, samples from India and Iran were among the lowest in amylopectin. U.S. samples were among the highest in amylopectin, as were those from Argentina, Colombia, and Portugal.

Short-grain.—The greatest amount of amylopectin, for all the milled rices examined, was in a sample from Egypt. The samples from Australia, Brazil, West Germany, Indonesia, and Portugal were among the highest in amylopectin. Ceylon samples had the lowest average. U.S. rices were close to the "all samples" average in this category.

Parboiled Milled Rice

United States, Burma, and Ghana samples were above average in amylopectin for this group. Long-grain and medium-grain averages were almost identical in amounts of amylopectin. With the exception of Burma, the average values for long- and medium-grain were practically the same in each country for which these analyses were made.

Amylose/Amylopectin Ratio

The calculated ratios of amylose to amylopectin, which are the two types of starch components found in rice, make more apparent the relationship of one starch constituent to the other, and permit a more pointed indication of the influence of small differences in starch makeup upon processing behavior of rices.

Table 21 shows a similar average amylose/amylopectin ratio for long- and medium-grain milled samples, and these average values were substantially higher than the average for milled short-grain rices.

The average ratio for parboiled milled long-grain was greater than for the medium-grain rices, and both these ratios were considerably higher than the corresponding milled rice values, but the ranges overlap.

Milled Rice

The most significant relationship was the finding that as the amylose/amylopectin ratio increased, there was a related increase in gelatinization temperature (table 27). Almost of equal significance were the findings that as amylose/amylopectin ratio increased, the values for alkali spreading, alkali clearing, and water uptake decreased.

There was evidence, throughout all grain lengths and for total samples, that as the amylose/amylopectin ratio increased, there was a decrease in iodine-blue values, with seeming more effect in long-grain lengths than in the shorter varieties.

For the most part, the amylose/amylopectin ratio was negatively related to sediment values (at both 77° C. and 82° C.).

At least in medium-grain rices, there was some indication of a possible inverse relationship between amylose/amylopectin ratio and color darkening—one increasing as the other decreased.

In longer types of rices, the amylose/amylopectin ratio became less as protein content increased.

As in the case for amylose, it was indicated that cooking quality appearance and flavor may be inversely related to the amylose/amylopectin ratio. Enough evidence was found regarding the effect of this ratio upon cooking quality cohesiveness (a positive correlation) to make additional studies desirable.

Long-grain.—West Pakistan samples averaged highest in this determination; other high averages were samples from India, Iran, Japan, Peru, and Thailand. Lowest values were found in samples from France, Greece, Italy, Portugal, and Turkey. U.S. rices had a lower average than the group average.

Medium-grain.—Samples from the United States, Argentina, and Colombia were among the lowest in average values. Those from Ceylon, India, and West Pakistan were highest, with West Pakistan having the highest value sample of any medium-grain rice.

Short-grain.—Samples from Ceylon and India had the highest amylose/amylopectin values; from Argentina, Australia, Brazil, Egypt, West Germany, Indonesia, and Portugal, the lowest U.S. samples were equivalent to the group's average.

Parboiled Milled Rice

The amylose/amylopectin ratios were higher, type for type, for parboiled samples than for the milled rices. East Pakistan samples had the highest value for both long- and medium-grain parboiled rice. Samples from Burma had the lowest value sample—and average—for long-grain parboiled. The samples from West Germany were lowest of the medium-grains.

TABLE 19.—AMYLOSE STARCH: *Number of samples, mean, and range of values for each country and "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	156	24.87	13.54–34.03	147	24.80	13.21–33.63	129	20.38	14.95–33.07
U.S.A	6	22.65	17.90–25.18	5	18.66	14.16–23.77	2	20.94	20.70–21.17
Africa, South	2	24.46	23.97–24.96	1	26.36	-----	2	20.72	19.66–21.79
Argentina	-----	-----	-----	4	14.34	13.21–15.39	4	18.62	17.70–19.82
Australia	-----	-----	-----	-----	-----	-----	1	18.72	-----
Brazil	7	22.04	17.53–23.84	5	19.31	15.73–21.65	3	18.61	17.56–19.16
Burma	8	20.10	13.54–27.40	35	24.73	16.67–30.52	-----	-----	-----
Ceylon	-----	-----	-----	7	28.28	26.55–29.54	3	28.15	27.29–29.56
Chile	-----	-----	-----	-----	-----	-----	-----	-----	-----
Colombia	4	22.92	21.03–24.22	1	18.39	-----	-----	-----	-----
Ecuador	2	24.44	23.93–24.94	4	26.40	23.38–28.09	-----	-----	-----
Egypt	-----	-----	-----	-----	-----	-----	5	18.99	14.95–26.13
El Salvador	-----	-----	-----	-----	-----	-----	-----	-----	-----
France	4	19.47	19.10–20.11	-----	-----	-----	2	22.84	22.57.23.12
Germany, West	5	21.94	18.98–24.15	4	22.40	19.67–24.81	3	17.96	16.48–20.58
Ghana	-----	-----	-----	-----	-----	-----	-----	-----	-----

Greece	6	16. 74	15. 92–17. 91	2	20. 21	20. 07–20. 35	8	19. 22	18. 07–20. 57
Guatemala	2	24. 49	22. 56–26. 42	-----	-----	-----	-----	-----	-----
India	19	28. 43	24. 16–34. 03	20	28. 66	24. 98–33. 63	8	27. 61	23. 95–33. 07
Indonesia	18	25. 12	20. 28–28. 65	8	25. 66	21. 98–28. 46	4	17. 79	17. 29–18. 14
Iran	9	26. 64	25. 38–29. 05	5	28. 19	21. 11–32. 70	1	21. 74	-----
Italy	6	15. 87	14. 36–17. 35	-----	-----	-----	3	20. 07	19. 91–20. 30
Ivory Coast	1	26. 31	-----	-----	-----	-----	1	22. 10	-----
Japan	6	27. 82	26. 39–28. 97	18	24. 26	18. 27–32. 52	60	19. 58	14. 95–24. 82
Korea	-----	-----	-----	-----	-----	-----	10	19. 49	18. 33–22. 06
Mexico	8	24. 31	20. 70–27. 86	-----	-----	-----	-----	-----	-----
Nigeria	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, East	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, West	11	31. 48	27. 34–33. 62	1	33. 56	-----	-----	-----	-----
Peru	6	26. 77	25. 19–28. 55	4	22. 62	17. 00–27. 97	-----	-----	-----
Philippines	-----	-----	-----	11	25. 36	21. 69–27. 85	-----	-----	-----
Portugal	1	17. 63	-----	3	19. 35	15. 67–22. 19	1	17. 94	-----
Spain	-----	-----	-----	-----	-----	-----	5	21. 37	16. 72–24. 66
Thailand	24	27. 02	21. 76–30. 16	6	27. 34	23. 42–30. 30	-----	-----	-----
Turkey	1	18. 43	-----	3	24. 74	24. 25–25. 64	3	24. 66	20. 06–29. 32

Continued

TABLE 19.—AMYLOSE STARCH: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	38	27.13	16.60–32.92	26	26.58	16.24–32.33
U.S.A.	1	25.40				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	19.29	16.60–22.21	8	24.03	20.34–27.67
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	16.46	16.24–16.68
Ghana	1	24.49				

Greece	--------	--------	--------	--------	--------	--------
Guatemala	--------	--------	--------	--------	--------	--------
India	6	28. 48	26. 36–30. 44	7	28. 96	27. 16–30. 70
Indonesia	--------	--------	--------	--------	--------	--------
Iran	--------	--------	--------	--------	--------	--------
Italy	--------	--------	--------	--------	--------	--------
Ivory Coast	--------	--------	--------	--------	--------	--------
Japan	--------	--------	--------	--------	--------	--------
Korea	--------	--------	--------	--------	--------	--------
Mexico	--------	--------	--------	--------	--------	--------
Nigeria	1	25. 15	--------	--------	--------	--------
Pakistan, East	6	31. 50	30. 50–32. 92	6	30. 00	28. 46–32. 33
Pakistan, West	6	29. 76	27. 14–32. 05	--------	--------	--------
Peru	--------	--------	--------	--------	--------	--------
Philippines	--------	--------	--------	--------	--------	--------
Portugal	--------	--------	--------	--------	--------	--------
Spain	--------	--------	--------	--------	--------	--------
Thailand	14	25. 70	22. 94–28. 71	3	27. 73	26. 84–28. 41
Turkey	--------	--------	--------	--------	--------	--------

TABLE 20.—AMYLOPECTIN STARCH: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*		*Percent*	*Percent*
"All samples"	156	62. 82	53. 95–72. 70	147	63. 38	55. 04–75. 35	129	68. 46	55. 71–76. 80
U.S.A.	6	65. 67	62. 30–71. 55	5	70. 49	65. 94–73. 35	2	69. 86	69. 28–70. 45
Africa, South	2	64. 00	63. 94–64. 06	1	64. 59	-----	2	70. 22	68. 68–71. 76
Argentina	-----	-----	-----	4	73. 56	72. 31–74. 57	4	69. 35	67. 20–70. 50
Australia	-----	-----	-----	-----	-----	-----	1	71. 36	-----
Brazil	7	65. 42	62. 05–69. 12	5	68. 96	63. 92–73. 03	3	70. 56	69. 86–71. 17
Burma	8	66. 08	58. 41–71. 91	35	62. 52	55. 61–72. 29	-----	-----	-----
Ceylon	-----	-----	-----	7	57. 98	55. 48–59. 29	3	57. 18	55. 71–59. 98
Chile	-----	-----	-----	-----	-----	-----	-----	-----	-----
Colombia	4	64. 47	63. 72–65. 37	1	71. 66	-----	-----	-----	-----
Ecuador	2	64. 41	63. 77–65. 05	4	61. 75	60. 15–64. 75	-----	-----	-----
Egypt	-----	-----	-----	-----	-----	-----	5	72. 06	65. 96–76. 80
El Salvador	-----	-----	-----	-----	-----	-----	-----	-----	-----
France	4	68. 64	67. 24–69. 83	-----	-----	-----	2	67. 18	66. 86–67. 50
Germany, West	5	64. 55	61. 72–70. 05	4	68. 00	66. 08–69. 56	3	70. 58	69. 11–71. 59
Ghana	-----	-----	-----	-----	-----	-----	-----	-----	-----

Greece	6	71.22	69.93–72.70	2	68.41	68.38–68.44	8	69.89	67.27–71.43
Guatemala	2	64.33	62.41–66.25	-----	-----	-----	-----	-----	-----
India	19	59.73	55.18–63.25	20	59.02	55.04–61.85	8	61.06	56.41–65.97
Indonesia	18	62.40	58.44–67.62	8	63.68	60.78–66.52	4	71.80	71.32–72.21
Iran	9	59.85	58.62–61.00	5	59.28	55.08–66.08	1	64.77	-----
Italy	6	68.96	62.07–72.20	-----	-----	-----	3	68.53	67.89–69.42
Ivory Coast	1	57.87	-----	-----	-----	-----	1	67.05	-----
Japan	6	61.81	60.74–63.21	18	65.43	56.09–71.24	60	69.27	63.54–73.18
Korea	-----	-----	-----	-----	-----	-----	10	69.35	68.04–70.24
Mexico	8	63.41	57.90–66.88	-----	-----	-----	-----	-----	-----
Nigeria	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, East	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pakistan, West	11	56.45	53.95–61.08	1	55.50	-----	-----	-----	-----
Peru	6	61.60	60.34–63.06	4	64.88	60.99–69.49	-----	-----	-----
Philippines	-----	-----	-----	11	63.38	60.34–68.63	-----	-----	-----
Portugal	1	72.01	-----	3	70.76	67.68–75.35	1	73.82	-----
Spain	-----	-----	-----	-----	-----	-----	5	65.27	61.50–69.69
Thailand	24	61.63	59.36–64.73	6	60.18	58.95–62.70	-----	-----	-----
Turkey	1	68.53	-----	3	63.30	62.32–64.87	3	63.78	58.62–69.00

Continued

TABLE 20.—AMYLOPECTIN STARCH: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Percent	*Percent*		*Percent*	*Percent*
"All samples"	38	59.99	53.82–70.11	26	60.07	54.06–72.20
U.S.A.	1	63.15				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	66.01	61.62–70.11	8	61.54	57.16–64.38
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	70.97	69.74–72.20
Ghana	1	64.89				

Greece						
Guatemala						
India	6	59. 00	57. 27–61. 56	7	59. 14	57. 51–60. 69
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria	1	61. 10				
Pakistan, East	6	54. 38	53. 82–55. 58	6	55. 54	54. 06–57. 13
Pakistan, West	6	57. 80	54. 22–61. 26			
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	61. 82	58. 39–66. 81	3	60. 14	59. 77–60. 62
Turkey						

TABLE 21.—AMYLOSE/AMYLOPECTIN RATIO: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
"All samples"	156	0.391	0.188–0.615	147	0.391	0.178–0.611	129	0.298	0.195–0.586
U.S.A.	6	.347	.250– .402	5	.267	.193– .360	2	.300	.294– .305
Africa, South	2	.382	.374– .390	1	.408		2	.296	.274– .317
Argentina				4	.195	.178– .213	4	.269	.251– .295
Australia							1	.262	
Brazil	7	.337	.249– .384	5	.282	.215– .339	3	.264	.247– .274
Burma	8	.307	.188– .438	35	.398	.231– .548			
Ceylon				7	.487	.466– .509	3	.493	.455– .529
Chile									
Colombia	4	.355	.321– .374	1	.256				
Ecuador	2	.379	.367– .391	4	.422	.361– .459			
Egypt							5	.267	.195– .396
El Salvador									
France	4	.284	.276– .299				2	.340	.334– .346
Germany, West	5	.341	.271– .391	4	.330	.283– .367	3	.252	.223– .298
Ghana									

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Greece	6	.235	.220- .256	2	.296	.293- .298	8	.272	.275- .300
Guatemala	2	.382	.341- .423	----	----	----	----	----	----
India	19	.479	.386- .615	20	.487	.429- .611	8	.456	.363- .586
Indonesia	18	.405	.300- .482	8	.404	.330- .459	4	.248	.242- .254
Iran	9	.445	.417- .477	5	.486	.320- .591	1	.336	----
Italy	6	.232	.199- .280	----	----	----	3	.293	.287- .297
Ivory Coast	1	.455	----	----	----	----	1	.330	----
Japan	6	.450	.428- .466	18	.376	.258- .580	60	.284	.204- .383
Korea	----	----	----	----	----	----	10	.281	.261- .324
Mexico	8	.386	.309- .481	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----	----	----	----
Pakistan, East	----	----	----	----	----	----	----	----	----
Pakistan, West	11	.560	.453- .612	1	.604	----	----	----	----
Peru	6	.435	.400- .465	4	.355	.245- .459	----	----	----
Philippines	----	----	----	11	.402	.316- .461	----	----	----
Portugal	1	.245	----	3	.276	.208- .328	1	.243	----
Spain	----	----	----	----	----	----	5	.331	.240- .396
Thailand	24	.439	.341- .508	6	.455	.391- .510	----	----	----
Turkey	1	.269	----	3	.391	.375- .409	3	.392	.291- .500

Continued

TABLE 21.—AMYLOSE/AMYLOPECTIN RATIO: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
"All samples"	38	0.458	0.250–0.611	26	0.448	0.225–0.595
U.S.A.	1	.402				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon	3	.294	.250– .360	8	.391	.315– .458
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West						
Ghana	1	.377		2	.232	.225– .239

Greece						
Guatemala						
India	6	.483	.432- .521	7	.490	.448- .533
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria	1	.412				
Pakistan, East	6	.579	.550- .611	6	.540	.500- .595
Pakistan, West	6	.518	.443- .579			
Peru						
Philippines						
Portugal						
Spain						
Thailand	14	.417	.344- .482	3	.461	.447- .475
Turkey						

Starch-Iodine-Blue Value

The reaction between amylose and iodine serves as the basis of the very useful starch-iodine-blue test in measuring an important varietal characteristic of rice. Starch-iodine-blue values were used by Roberts and others (*40*) to estimate the degree of parboiling in rice. Varietal differences in parboiled rice were also observed by these investigators. It was later shown (*17*) that this test could be used to determine varietal differences in raw milled rice by cooking the ground rice in water at 77° C. for 45 minutes. The intensity of the blue color produced by the addition of dilute iodine solution is indicative of the amylose leached from or diffused from ground rice under the conditions of the test. As stated previously, the starch-iodine-blue test also provides for the detection of varieties having abnormally high gelatinization temperatures.

It is recognized that the iodine-blue value of a particular rice variety may be influenced by the location of growth, the environmental conditions during growth and maturity, the degree of milling and polishing, the age and condition under which the paddy and milled rice were stored, and possibly by many other factors. However, when the varieties are grown under comparable conditions and are treated uniformly, certain comparisons can be made. Williams and others (*45*) reported a high correlation between the iodine-blue values and quantitative amylose data for rice varieties grown under comparable conditions and treated uniformly.

Since information concerning the cultural background, harvesting, postharvest treatment, and storage of the foreign samples used in this study was not available, the data on iodine-blue values, summarized in table 22, are not as meaningful as desired. For example, by plotting one variable (iodine-blue) against another (amylose), a rough linear relationship can be shown but with considerable scattering of points, and indeed some extreme cases were found in this study where no apparent relationship exists. Therefore, in this study the iodine-blue value of a particular sample might lead to a false conclusion in estimating the relative amylose content of particular samples.

Milled Rice

In general, the milled long-grain rices used in this study had somewhat higher iodine-blue values than either the medium- or the short-grain samples.

As iodine-blue values increased, color (lightness) decreased; e.g., the darker the sample the greater the iodine-blue number (table 27). For medium-grain rices, at least, improved appearance after cooking seemed to accompany increased iodine-blue numbers. In long-grain rices, as iodine-blue values increased, there was increased stickiness after cooking.

Iodine-blue values seemed inversely related to kernel length, particularly as shown by the negative correlation between iodine-blue and kernel length in short-grain rices.

Long-grain.—U.S. samples averaged close to that for all the foreign rices in iodine-blue values. Samples from Burma, Greece, Italy, West Pakistan, and Turkey had highest average values; from Guatemala, Iran, Japan, and Thailand, the lowest average values.

Medium-grain.—Samples from the United States, Brazil, and Ceylon had very high averages, exceeded only by the group from Argentina. Colombia, Iran, and the Philippines had the lowest for this group of samples.

Short-grain. In this category, the Ceylon samples were highest. Again Iran had one of the lowest averages. U.S. rices were considerably below the average for the group.

Parboiled Milled Rice

Average iodine-blue values for parboiled samples were half again higher than values for the milled samples (table 22). The U.S. sample was among the lowest iodine-blue values. Five countries—Ghana, Nigeria, East and West Pakistan, and Thailand—had values above 70 in the long-grain category. In medium-grain rices, Burma and East Pakistan had iodine-blue values of 80 or above.

TABLE 22.—IODINE-BLUE VALUE: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
"All samples"	164	38	7–78	148	33	7–82	129	36	13–72
U.S.A.	6	36	25–57	5	50	27–71	2	24	23–26
Africa, South	2	32	28–37	1	34		2	36	34–37
Argentina	2	43	41–45	5	73	44–82	4	37	35–40
Australia							1	14	
Brazil	7	34	24–56	5	51	38–57	3	47	44–51
Burma	11	59	27–73	35	27	15–54			
Ceylon				7	55	32–81	3	58	37–72
Chile									
Colombia	4	27	11–53	1	18				
Ecuador	2	32	27–37	4	27	21–31			
Egypt							5	36	18–62
El Salvador	2	48	17–78						
France	4	48	29–65				2	32	29–34
Germany, West	5	36	26–47	4	30	24–40	3	40	29–49
Ghana									

Greece	6	58	50–70	2	26	22–30	8	28	24–37
Guatemala	2	24	24–25	------	------	------	------	------	------
India	20	31	13–62	21	40	7–72	8	38	24–55
Indonesia	18	47	26–65	8	40	29–50	4	40	32–54
Iran	9	24	23–25	5	16	13–20	1	15	------
Italy	6	55	46–62	------	------	------	3	26	25–26
Ivory Coast	1	35	------	------	------	------	1	24	------
Japan	6	24	16–32	18	27	11–43	60	39	22–60
Korea	------	------	------	------	------	------	10	29	18–38
Mexico	9	30	21–44	------	------	------	------	------	------
Nigeria	------	------	------	------	------	------	------	------	------
Pakistan, East	------	------	------	------	------	------	------	------	------
Pakistan, West	11	55	47–72	1	40	------	------	------	------
Peru	6	32	12–48	4	41	13–61	------	------	------
Philippines	------	------	------	11	14	8–17	------	------	------
Portugal	1	37	------	2	26	22–30	1	25	------
Spain	------	------	------	------	------	------	5	35	22–55
Thailand	23	26	7–37	6	28	9–47	------	------	------
Turkey	1	54	------	3	31	20–37	3	21	13–27

Continued

TABLE 22.—IODINE-BLUE VALUE: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
"All samples"	38	54	18–86	26	53	17–87
U.S.A.	1	27				
Africa, South						
Argentina						
Australia						
Brazil						
Burma	3	56	54–60	8	68	28–87
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	32	29–35
Ghana	1	73				

Greece	-	-	-	-	-	-
Guatemala	-	-	-	-	-	-
India	6	41	27–68	7	34	17–68
Indonesia	-	-	-	-	-	-
Iran	-	-	-	-	-	-
Italy	-	-	-	-	-	-
Ivory Coast	-	-	-	-	-	-
Japan	-	-	-	-	-	-
Korea	-	-	-	-	-	-
Mexico	-	-	-	-	-	-
Nigeria	1	77	-	-	-	-
Pakistan, East	6	68	62–75	6	70	57–80
Pakistan, West	6	69	50–86	-	-	-
Peru	-	-	-	-	-	-
Philippines	-	-	-	-	-	-
Portugal	-	-	-	-	-	-
Spain	-	-	-	-	-	-
Thailand	14	46	18–71	3	33	20–58
Turkey	-	-	-	-	-	-

Palatability Characteristics (After Cooking)

Appearance

Milled Rice

Distinct differences in the appearance of rices from various countries were noted after cooking. Appearance values of kernels after cooking, for the various countries, are indicated in table 23.

Differences in appearance scores of the rices were greater among individual lots from different countries than among long-, medium-, and short-grain varieties from one country, as shown by the overlapping ranges among grain types within most of the countries. In contrast to some foreign rices, the U.S. long-, medium-, and short-grain rice samples had similar appearance scores. A tendency for the long-grain kernels to split longitudinally and for the short-grain samples to slough was noted (fig. 19).

Long-grain.—Samples from Indonesia had the lowest values, being below the average of 6.3. The United States, India, and Iran rices exhibited the highest appearance scores. Long-grain rices had the widest range of appearance scores of any of the three types.

Medium-grain.—U.S. rices in this class had the highest appearance scores, whereas the India sample was the lowest.

Short-grain.—These samples averaged the same as medium-grain rices, but this may be a mathematical coincidence. Here again, the U.S. samples averaged a high rating, exceeded only slightly by one sample obtained from Argentina.

Parboiled Milled Rice

The cooked samples of parboiled rice from West Germany, India, East Pakistan, and the United States had whole smooth grains. Parboiled milled rices had higher scores for appearance than did milled samples. It was shown that parboiled milled rices increased in volume, but otherwise changed little in appearance during cooking. Parboiled samples showed this same general behavior and appearance even when subjected to more drastic treatment of additional soaking prior to cooking (fig. 19).

Cohesiveness

Milled Rice

A wide range in the cohesiveness of cooked milled rices was noted among the rice varieties from the different countries (table 24). Cooked grains of most of the rice samples were either partially separated (scale value 7) or were slightly sticky and clumped (scale value 5). It was of interest to note that the most cohesive sample (3.2) and the least cohesive one (8.9) both came from India.

These investigations showed increasing cohesiveness from long- to medium- to short-grain types of rices. Range in cohesiveness scores was widest for long-grain rice and least for short-grain rice (table 24). The range in scores for cohesiveness for the foreign rices was somewhat wider than for the samples from the United States. Differences in cohesiveness were greater within a grain type (among individual lots from different countries) than among grain types from within a country, as illustrated by the overlapping ranges. This may be related to the origin of these rices, as discussed under starch constituents in this report.

A consistent negative correlation existed between cooking quality cohesiveness and sediment at 77° C. and 82° C. (table 27).

A negative correlation was found to exist, in "all samples" and medium-grain rices, between cooking quality cohesiveness and alkali clearing, alkali spreading, and water uptake (77° C. and 82° C.).

Long-grain. Samples from Brazil, West Germany, India, Iran, and Peru were less sticky than those from the United States. The most cohesive long-grain samples evaluated came from Greece, Indonesia, Italy, and Mexico.

Medium-grain.—Samples from India, Portugal, and Japan were the most cohesive in this type; those from Thailand, Indonesia, Ecuador, and Burma, the least cohesive; rices from the United States, Argentina, and Iran were intermediate in such values.

Short-grain.—Rices from Egypt, Australia, and West Germany were the stickiest; those from Argentina and Iran, the least sticky; and those from the United States, France, Greece, Iran, Italy, Japan, and Korea were between these extremes.

Parboiled Milled Rice

The parboiled cooked rices had more well-separated grains and were less sticky or cohesive than the regular milled rice samples. The cooked samples of parboiled rices from West Germany, India, East Pakistan, and the United States had well-separated grains. In fact, all parboiled samples (cooked) examined had exceedingly low cohesiveness values.

TABLE 23.—PALATABILITY CHARACTERISTIC—APPEARANCE: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*		*Scores*	*Scores*
"All samples"	27	6. 3	3. 8–8. 8	20	6. 0	2. 8–7. 3	39	6. 0	4. 8–7. 2
U.S.A	6	7. 4	6. 9–7. 8	5	6. 7	6. 2–7. 3	2	6. 6	6. 4–6. 7
Africa, South	--	--	--	--	--	--	--	--	--
Argentina	--	--	--	1	6. 4	--	1	7. 0	--
Australia	--	--	--	--	--	--	1	4. 9	--
Brazil	2	6. 9	6. 7–7. 1	1	6. 6	--	--	--	--
Burma	--	--	--	1	6. 7	--	--	--	--
Ceylon	--	--	--	--	--	--	--	--	--
Chile	--	--	--	--	--	--	--	--	--
Colombia	--	--	--	--	--	--	--	--	--
Ecuador	--	--	--	2	5. 8	5. 8–5. 9	--	--	--
Egypt	--	--	--	--	--	--	1	5. 4	--
El Salvador	--	--	--	--	--	--	--	--	--
France	--	--	--	--	--	--	2	6. 1	5. 9–6. 3
Germany, West	2	6. 9	6. 5–7. 3	--	--	--	1	5. 0	--
Ghana	--	--	--	--	--	--	--	--	--

Greece	1	7.4	-------	-------	-------	-------	2	5.7	5.3–6.1
Guatemala	-------	-------	-------	-------	-------	-------	-------	-------	-------
India	3	8.8	8.8–8.8	1	2.8	-------	-------	-------	-------
Indonesia	8	4.4	3.8–5.6	2	6.0	5.4–6.5	-------	-------	-------
Iran	1	7.9	-------	1	5.6	-------	1	5.6	-------
Italy	2	6.6	6.6–6.7	-------	-------	-------	2	6.1	6.0–6.2
Ivory Coast	-------	-------	-------	-------	-------	-------	-------	-------	-------
Japan	-------	-------	-------	3	5.9	5.8–6.0	18	6.2	5.1–6.9
Korea	-------	-------	-------	-------	-------	-------	6	6.0	4.8–7.2
Mexico	2	6.0	5.8–6.1	-------	-------	-------	-------	-------	-------
Nigeria	-------	-------	-------	-------	-------	-------	-------	-------	-------
Pakistan, East	-------	-------	-------	-------	-------	-------	-------	-------	-------
Pakistan, West	-------	-------	-------	-------	-------	-------	-------	-------	-------
Peru	1	5.2	-------	-------	-------	-------	-------	-------	-------
Philippines	-------	-------	-------	-------	-------	-------	-------	-------	-------
Portugal	-------	-------	-------	2	5.4	5.3–5.5	-------	-------	-------
Spain	-------	-------	-------	-------	-------	-------	2	5.4	5.3–5.4
Thailand	-------	-------	-------	1	6.4	-------	-------	-------	-------
Turkey	-------	-------	-------	-------	-------	-------	-------	-------	-------

Continued

TABLE 23.—PALATABILITY CHARACTERISTIC—APPEARANCE: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*
"All samples"	4	8. 9	8. 8–9. 0	5	8. 6	8. 4–8. 9
U.S.A	1	8. 9				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	8. 7	8. 5–8. 9
Ghana						

Greece						
Guatemala						
India	2	8.9	8.8–9.0	2	8.6	8.4–8.9
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	1	8.8			8.5	
Pakistan, West						
Peru						
Philippines						
Portugal						
Spain						
Thailand						
Turkey						

TABLE 24.—PALATABILITY CHARACTERISTIC—COHESIVENESS: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*		*Scores*	*Scores*
"All samples"	27	5. 6	3. 6–8. 9	20	5. 0	3. 2–6. 5	39	4. 5	3. 2–6. 1
U.S.A	6	5. 7	5. 1–6. 1	5	4. 7	3. 8–6. 1	2	4. 0	3. 6–4. 4
Africa, South									
Argentina				1	5. 3		1	5. 5	
Australia							1	3. 6	
Brazil	2	6. 6	6. 2–6. 9	1	4. 7				
Burma				1	5. 9				
Ceylon									
Chile									
Colombia									
Ecuador				2	6. 0	5. 9–6. 0			
Egypt							1	3. 2	
El Salvador									
France							2	4. 7	4. 7–4. 7
Germany, West	2	6. 4	6. 2–6. 5				1	3. 4	
Ghana									

Greece	1	4. 9					2	4. 2	3. 5–4. 8
Guatemala									
India	2	8. 7	8. 6–8. 9	1	3. 2				
Indonesia	8	4. 4	3. 6–5. 2	2	6. 4	6. 4–6. 5	1	5. 3	
Iran	1	7. 7		1	5. 5		2	4. 6	4. 5–4. 7
Italy	2	5. 0	4. 7–5. 2						
Ivory Coast							18	4. 7	3. 6–6. 1
Japan				3	4. 1	3. 6–4. 9	6	4. 3	3. 3–5. 0
Korea									
Mexico	2	4. 8	4. 8–4. 9						
Nigeria									
Pakistan, East									
Pakistan, West									
Peru	1	5. 8							
Philippines									
Portugal				2	3. 8	3. 7–3. 9	2	4. 2	3. 9–4. 4
Spain									
Thailand				1	6. 9				
Turkey									

Continued

TABLE 24.—PALATABILITY CHARACTERISTIC—COHESIVENESS: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*
"All samples"	3	8. 8	8. 8–8. 9	5	8. 7	8. 4–9. 0
U.S.A	1	8. 9				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West						
Ghana				2	8. 8	8. 6–9. 0

Greece						
Guatemala						
India	1	8. 8		2	8. 6	8. 4–8. 9
Indonesia						
Iran						
Italy						
Ivory Coast						
Japan						
Korea						
Mexico						
Nigeria						
Pakistan, East	1	8. 8		1	8. 6	
Pakistan, West						
Peru						
Philippines						
Portugal						
Spain						
Thailand						
Turkey						

Tenderness

Milled Rice

Most of the cooked rice samples were fairly tender and firm (optimum doneness), represented by scale value 5. In accordance with practical use experience, the results of these tests showed a changing direction from firmness and chewiness in long-grain rices to softer textures for medium- and short-grain types.

In general, the parboiled samples were slightly more firm and chewy than the regular milled rices after cooking. A fairly wide range of tenderness score was evident in both milled and parboiled samples (table 25).

A rather consistent relationship was found, in this study, between lipid content and tenderness (table 27). As surface and total lipids, particularly the total lipids, increased, cooking tenderness texture was improved. It would seem that additional research should be directed to determining the kinds of lipids and the specific reactions, if any, between these lipids and other rice constituents to account for quality behavioral characteristics, especially those affecting tenderness.

Sufficient negative correlation seemed to exist between cooking quality tenderness and water uptake (at 82° C.) in total and medium-grain rices to justify further study of this relationship. About the same degree of negative correlation was found between cooking tenderness and sediment at 77° C. for total and short-grain rices; a lesser relationship was indicated between tenderness and sediment at 82° C. A somewhat similar relationship was found for tenderness and water uptake at 82° C. for "all samples" and medium-grain rices. The possibility of an overall relation concerning cooking quality tenderness and the quality factors of cohesiveness and flavor should be studied further.

Long-grain—Rices from Brazil, Indonesia, and Italy had the highest degree of firmness after cooking. Those from the United States, West Germany, India, Iran, Greece, and Mexico averaged midway, with the lowest values (softest) being a U.S. sample, one from Indonesia, and one from Peru.

Medium-grain—Samples from the United States and Japan were quite similar in tenderness quality, and corresponded with the average for this group. The one medium-grain sample from India was very soft and mushy (1.6).

Short-grain—Rices from Argentina, Australia, Japan, Korea, Spain, and the United States were practically identical in tenderness scores.

Parboiled Milled Rice

The parboiled rices evaluated were somewhat less tender after cooking than the regular milled rices. However, too few samples were tested to make generalizations.

Flavor

Very pronounced flavors, not typical of most U.S. rices, were evident in the rices from many of the foreign countries. These flavors found in cooked rices were attributed to such factors as: Storage conditions, milling or parboiling, fermentation during the parboiling process, and the inherent "flavor" of many Asiatic rice varieties.

Of all samples taste-tested, the U.S. long-grain samples were the only ones receiving a perfect score (9.0); medium- and short-grain rices from the United States averaged 8.2 and 8.6 (table 26).

Milled Rice

It was observed that for "all samples" the milled short-grain rices averaged highest in flavor evaluation, with slightly lower average value for medium-grain, and the long-grain samples averaging the lowest.

Long-grain.—U.S. rices had the highest score, (with a near-perfect average rating of 8.9). Other very high-rating samples were those from West Germany, Greece, Iran, and Mexico. The lowest rated samples were from India, Indonesia, and Peru.

Medium-grain.—Samples from the United States, Argentina, Brazil, and Portugal averaged highest (above 8.0). The medium-grain rices had a rather narrow range, and most were considered to be of fairly good quality.

Short-grain.—These samples not only averaged the highest score in flavor, but nearly all samples tested were consistently good. Samples from the United States, Egypt, Australia, France, West Germany, Greece, Italy, and Korea ranked highest.

Parboiled Milled Rice

The foreign parboiled samples evaluated had rather low flavor scores. The long-grain samples averaged somewhat higher than the medium-grain samples, but all had slight to moderately strong off-flavors. The U.S. parboiled sample had an acceptable flavor rating of 7.2.

TABLE 25.—PALATABILITY CHARACTERISTIC—TENDERNESS: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Scores	*Scores*		*Scores*	*Scores*		*Scores*	*Scores*
"All samples"	26	5. 8	4. 2–7. 7	20	5. 0	1–6–6. 0	39	5. 1	3. 4–6. 3
U.S.A	6	5. 1	4. 2–6. 0	5	5. 1	4. 7–5. 8	2	5. 0	4. 9–5. 1
Africa, South									
Argentina				1	4. 7		1	5. 1	
Australia							1	5. 0	
Brazil	2	6. 6	6. 5–6. 8	1	4. 7				
Burma				1	4. 8				
Ceylon									
Chile									
Colombia									
Ecuador				2	5. 4	5. 4–5. 4			
Egypt							1	4. 7	
El Salvador									
France							2	4. 6	4. 3–4. 8
Germany, West	2	5. 4	4. 5–6. 2				1	3. 4	
Ghana									

Greece	1	5.6	-	-	-	-	2	4.4	3.9–4.9
Guatemala	-	-	-	-	-	-	-	-	-
India	2	5.8	5.7–6.3	1	1.6	-	-	-	-
Indonesia	8	6.5	4.3–7.7	2	5.9	5.8–6.0	-	-	-
Iran	1	5.2	-	1	5.7	-	1	6.1	-
Italy	2	6.2	5.6–6.9	-	-	-	2	5.9	5.6–6.2
Ivory Coast	-	-	-	-	-	-	-	-	-
Japan	-	-	-	3	5.2	4.6–5.8	18	5.2	3.5–6.3
Korea	-	-	-	-	-	-	6	5.2	4.9–5.7
Mexico	2	5.7	4.9–6.5	-	-	-	-	-	-
Nigeria	-	-	-	-	-	-	-	-	-
Pakistan, East	-	-	-	-	-	-	-	-	-
Pakistan, West	-	-	-	-	-	-	-	-	-
Peru	1	4.2		-	-	-	-	-	-
Philippines	-	-	-	-	-	-	-	-	-
Portugal	-	-	-	2	5.2	4.5–5.8	-	-	-
Spain	-	-	-	-	-	-	2	4.9	4.7–5.1
Thailand	-	-	-	-	-	-	-	-	-
Turkey	-	-	-	-	-	-	-	-	-

Continued

TABLE 25.—PALATABILITY CHARACTERISTIC—TENDERNESS: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Scores	*Score*		*Scores*	*Score*
"All samples"	4	5. 5	4. 6–6. 3	5	5. 6	4. 1–7. 0
U.S.A.	1	6. 3				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	6. 8	6. 7–7. 0
Ghana						

Greece	----	----	----	----	----	----
Guatemala	----	----	----	----	----	----
India	2	5. 4	4. 6–6. 3	2	4. 6	4. 1–5. 1
Indonesia	----	----	----	----	----	----
Iran	----	----	----	----	----	----
Italy	----	----	----	----	----	----
Ivory Coast	----	----	----	----	----	----
Japan	----	----	----	----	----	----
Korea	----	----	----	----	----	----
Mexico	----	----	----	----	----	----
Nigeria	----	----	----	----	----	----
Pakistan, East	1	4. 7	----	1	5. 1	----
Pakistan, West	----	----	----	----	----	----
Peru	----	----	----	----	----	----
Philippines	----	----	----	----	----	----
Portugal	----	----	----	----	----	----
Spain	----	----	----	----	----	----
Thailand	----	----	----	----	----	----
Turkey	----	----	----	----	----	----

TABLE 26.—PALATABILITY CHARACTERISTIC—FLAVOR: *Number of samples, mean, and range of values for each country and for "all samples"*

Country	Milled rice								
	Long-grain			Medium-grain			Short-grain		
	Number	Mean	Range	Number	Mean	Range	Number	Mean	Range
		Score	*Score*		*Score*	*Score*		*Score*	*Score*
"All samples"	27	7. 0	1. 7–9. 0	20	7. 7	6. 2–8. 9	39	7. 8	5. 1–8. 9
U.S.A	6	8. 9	8. 5–9. 0	5	8. 2	6. 7–8. 9	2	8. 6	8. 2–8. 9
Africa, South									
Argentina				1	8. 2		1	6. 2	
Australia							1	8. 1	
Brazil	2	6. 2	5. 5–6. 8	1	8. 6				
Burma				1	7. 3				
Ceylon									
Chile									
Colombia									
Ecuador									
Egypt				2	6. 4	6. 3–6. 6			
El Salvador							1	8. 6	
France									
Germany, West	2	7. 6	7. 1–8. 0				2	7. 8	7. 2–8. 4
Ghana							1	8. 8	

Greece	1	8. 1					2	8. 5	8. 4–8. 6
Guatemala									
India	2	5. 3	4. 6–6. 0	1	7. 0				
Indonesia	8	5. 7	1. 7–7. 7	2	7. 9	7. 5–8. 3			
Iran	1	8. 4		1	6. 2		1	5. 1	
Italy	2	7. 4	7. 3–7. 6				2	8. 0	7. 9–8. 1
Ivory Coast									
Japan				3	7. 8	7. 1–8. 4	18	7. 6	6. 3–8. 7
Korea							6	8. 2	7. 7–8. 9
Mexico	2	8. 0	7. 6–8. 4						
Nigeria									
Pakistan, East									
Pakistan, West									
Peru	1	5. 0							
Philippines									
Portugal				2	8. 4	8. 2–8. 5			
Spain							2	7. 6	7. 5–7. 6
Thailand				1	7. 6				
Turkey									

Continued

TABLE 26.—PALATABILITY CHARACTERISTIC—FLAVOR: *Number of samples, mean, and range of values for each country and for "all samples"*—Continued

Country	Parboiled milled rice					
	Long-grain			Medium-grain		
	Number	Mean	Range	Number	Mean	Range
		Score	*Score*		*Score*	*Score*
"All samples"	4	5. 2	3. 7–7. 2	5	4. 6	2. 6–6. 5
U.S.A	1	7. 2				
Africa, South						
Argentina						
Australia						
Brazil						
Burma						
Ceylon						
Chile						
Colombia						
Ecuador						
Egypt						
El Salvador						
France						
Germany, West				2	6. 0	5. 4–6. 5
Ghana						

Greece	--	--	--	--	--	--
Guatemala	--	--	--	--	--	--
India	2	4. 4	3. 7–5. 1	2	4. 2	3. 4–4. 9
Indonesia	--	--	--	--	--	--
Iran	--	--	--	--	--	--
Italy	--	--	--	--	--	--
Ivory Coast	--	--	--	--	--	--
Japan	--	--	--	--	--	--
Korea	--	--	--	--	--	--
Mexico	--	--	--	--	--	--
Nigeria	--	--	--	--	--	--
Pakistan, East	1	4. 8	--	1	2. 6	--
Pakistan, West	--	--	--	--	--	--
Peru	--	--	--	--	--	--
Philippines	--	--	--	--	--	--
Portugal	--	--	--	--	--	--
Spain	--	--	--	--	--	--
Thailand	--	--	--	--	--	--
Turkey	--	--	--	--	--	--

PART IV.—INTERRELATIONSHIPS

The voluminous technical data—both objective and subjective measurements—have been subjected to detailed statistical studies in an effort to establish possible correlations between these various factors of foreign and domestic rices. (See table 27.) These studies (a) revealed certain significant correlations, (b) indicated interesting trends, and (c) pointed out the need for further research to better establish certain relationships and to simplify the technical procedures for fully characterizing rice cooking and processing qualities.

One of the objectives of these investigations was to characterize the rices according to: (a) grain length (long-, medium-, or short-grain); (b) treatment (raw milled, parboiled, and others); and (c) country in which the samples were obtained. However, in many instances there were fewer than the minimum five samples required for any sort of statistical treatment—in fact, in many cases there were no samples at all for a particular category. On the other hand, in some classifications the number of samples was so large that, from a mathematical standpoint, at least, correlation coefficients were obtained that indicated existence of significant relationships which seemed to have little scientific justification but apparently were mathematical happenstances.

For the reasons just enumerated, the principal discussions of correlations have been limited to classifications within the broad categories of grain lengths plus a combined "all samples" classification (combined long-, medium-, and short-grain rices). Such groupings of the samples have permitted more meaningful interpretation of the technical data.

In this part of the report, the broad interrelationships between the various quality factors are pointed out and cognizance is taken of the seemingly contradictory results sometimes indicated in comparing long-, medium-, and short-grain rices.

Physical Measurements

Since world markets place much emphasis on grain length as a criterion of quality, it would be expected that many relationships might be found between *grain lengths* and other quality factors. Under the arbitrary grain-length classifications (accepted in the United States) used in this study, however, not many such significant relationships were found.

There was not a single example of kernel length being consistently and significantly correlated with 1 of the 25 other quality factors across all length classifications (combined, long-, medium-, and short-grains). There were indications, however, suggesting a positive correlation between kernel length and palatability cohesiveness, especially in the medium-grain rices; short-grain rices exhibited some relation between length and heat alteration (table 27).

Many varietal differences were apparent that were not associated with grain length. For instance, although the long-grain rices to which U.S. consumers are accustomed are usually not very cohesive or sticky, and short-grain rices tend to be very cohesive, in this investigation there were many exceptions. Only about 20 percent of the variation in the cohesiveness scores was associated with kernel length, whereas 80 percent was related to other factors. These findings have a counterpart in a previous study on 26 varieties of milled U.S. rices in which several long-grain types were found to be more cohesive than the short-grain types (*5*).

Kernel width could not be significantly correlated with any of the 25 factors. Other studies, however, have shown that the combination of various shape factors—length, width, thickness, and general contour—have an important bearing on consumer preference.

Color ("L" value for lightness) of rice was negatively correlated with surface lipids—in all grain lengths—and positively with water uptake and sediment. Surface lipid content and color are recognized as partly dependent upon the degree of milling, and it may be that removal of the outer protective layers by milling would make the rice more amenable to water absorption.

Thermal and Chemical Reactions

A substantial number of correlations were found among the quality factors involving thermal and chemical reactions (table 27).

These studies have given strong indications that *gelatinization temperature* may be significantly correlated with such measurements as alkali spreading, alkali clearing, water uptake, heat alteration, amylose/amylopectin ratio, and palatability cohesiveness. These findings are consistent with those reported by other researchers who found that the gelatinization properties were related to the cohesiveness of cooked rice, and that cohesiveness was associated with the manner in which rice responds to treatment in other processes. The possibility is envisioned that some sort of gelatinization temperature determination may offer one of the greatest opportunities for a single, simplified procedure that would adequately predict the cooking and processing characteristics of rices.

These studies revealed a low but consistent relation between *heat alteration* and gelatinization temperature for total, long-, medium-, and short-grain types of rice. Also, heat alteration was found to be somewhat related to several other quality factors—alkali spreading and clearing, and water uptake.

Water uptake and *sedimentation* are interrelated by virtue of the technical procedure for making the determinations, and were found in these investigations to be related to several other measurements such as alkali spreading and clearing, and palatability cohesiveness. Water uptake at 77° C. was not as significantly related to water uptake at 82° C. as were the sediment values at these two temperatures.

Response of rice to treatment with an alkaline solution was associated with many of the other characteristics, particularly those involving heat. More than 60 percent of the variation in either *alkali spreading* or *alkali clearing* was associated with gelatinization temperature, heat alteration values, and water uptake at 77° C. Either alkali spreading value or alkali clearing value could be used in measuring rice quality, since 93 percent of variation in the alkali spreading score was associated with the variation in the alkali clearing score.

Chemical Determinations

Surface lipids, which in this study averaged about 60 percent of *total lipids*, has long been recognized as indicative of the degree of milling. Palatability appearance is affected by surface lipid content, although there does not seem to be a uniform trend in all grain lengths. As surface lipids decreased, and to a lesser extent total lipids, color (lightness) increased (table 27). Although many researchers have believed that palatability cohesiveness is influenced by surface lipids, these studies did not show any consistent pattern of such behavior. Interestingly enough, the effect of surface lipids seemed to be in opposite direction for long-grain rice to that for short-grain rice.

Although the *protein* fractions constitute less than 10 percent by weight of the milled kernel, the protein and the amino acid patterns are known to differ considerably among varieties or types (*4, 8, 26*).[10] Previous studies have been devoted to evaluating the essential amino acids with reference to the nutritive value of rice varieties (*25*). The textural qualities of cooked rice also are likely to be influenced by the protein and amino acid patterns and their differential reactions to heat. The nitrogen determinations reported in this study represent only a beginning, since nitrogen determinations give no indication of the relative amounts in which proteins or amino acids may be present.

In this study, only about one-fourth of the variation in protein content of rice was associated with grain length (table 27). Less correlation was found between protein content and any of the other 24 characteristics included in the investigation. The kinds of protein and the distribution of protein, rather than total protein content, have been suggested as more likely influences contributing to the cooking characteristics of rice (*28*).

One of the most important factors affecting the quality of rice, particularly during storage, is *moisture*. However, since practically nothing was known about the cultural, handling, and storage conditions prior to obtaining the samples, this important factor could be given little consideration in these evaluation studies.

Nearly half of the variation in the amount of water absorbed at 77° C. can be related to the *amylose* or *amylopectin* content of the rice or to the ratio between the two starch fractions (table 27). There was less correlation for water absorbed at 82° C. With an increase in amylose and a corresponding decrease in amylopectin, less water was absorbed by the rices.

About one-fourth of the variation in alkali spreading and clearing values was associated with the starch fractions of amylose and amylopectin. A slightly better relationship was found between amylopectin and the alkali clearing value than between amylose and alkali

[10] See also footnote 4, p. 6.

clearing (table 27). Samples with high amylopectin content (low amylose) had low clearing values.

These investigations did not reveal any consistent pattern of the effect of amylose or amylopectin content upon the palatability characteristics of rice (table 27). Other researchers (*17, 38, 45*), however, have reported relationships between amylose content and certain cooking and palatability traits; some have suggested that the molecular weight of the amylose fractions may be governing factors.

Over a third of the variation in gelatinization temperature has been shown to be related to the *amylose/amylopectin ratio* (table 27). As the ratio increased, the gelatinization temperature increased. Previous studies (*16*) have pointed out that gelatinization temperature is not dependent on the amount of amylose; e.g., Century Patna and Toro rices contain similar amounts of amylose but have quite different gelatinization temperature.

The *iodine-blue value* indicates the amylose in the rice that is soluble under the conditions of the test. However, these studies did not show as close a relationship between iodine-blue and the amylose content as expected (table 27). There was a fair correlation between iodine-blue and the amylose amylopectin ratio values. There seemed to be a higher degree of correlation between color (lightness) and the iodine-blue determinations.

Palatability Characteristics (After Cooking)

In the palatability investigations, an attempt was made to cook all the samples to optimum doneness. If the samples had been cooked for a certain period of time in a specified volume of water, rather than to optimum doneness, some of the palatability relationships—especially cohesiveness and tenderness—might have been entirely different.

Color (lightness) values of raw milled rice apparently were not significantly related to *appearance* of cooked rice. Long-grain samples with low lipid contents were given high scores for appearance after cooking, but the reverse was noted for short-grain rices. This relation is probably a reflection of the degree of milling. In general, high scores for appearance were associated with low percentages of broken kernels (table 27).

Cohesiveness of cooked rice seemed to be dependent on many factors. No single characteristic of rice included in this research was related to more than 50 percent of the variation in cohesiveness scores. About one-third of the variation in cohesiveness scores of cooked rice was associated with the gelatinization temperature, water absorption at 77° C., sediment at 77° C., or the heat alteration value (table 27).

Less than a fifth of the variation in scores for *tenderness* of cooked rice was associated with any of the other factors included in this project. More of the variation in tenderness scores of short-grain cooked rice was associated with the surface and total lipid content, but this was probably a reflection of the degree of milling.

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TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Kernel length:								
Broken kernels	422	0.199*	152	−0.186	147	0.189	123	−0.183
Surface lipids			155	−.173				
Total lipids					103	.235		
Protein	441	.503*	155	.511*			127	−.280*
Amylose	441	.308*	155	−.220*			127	−.236*
Amylopectin	441	−.381*					127	.307*
Amylose/amylopectin ratio	441	.326*	155	−.214*			127	−.207*
Iodine-blue value							127	−.494*
Alkali spreading	156	−.392*					45	.696*
Alkali clearing	156	−.430*			56	−.278	45	.731*
Water uptake—77° C	471	−.451*					126	.257*
Water uptake—82° C	472	−.140*					127	.348*
Sediment—77° C	471	−.217*					126	.230*
Sediment—82° C							127	.290*
Palatability—Cohesiveness	87	.454*			24	.521*		
Palatability—Tenderness	87	.365*						
Gelatinization temperature	181	.366*	71	−.254			39	−.338*
Heat alteration	216	−.501*					71	−.475*
Kernel width: Broken kernels	422	−.253*			147	−.279*	123	−.280*

Broken kernels:								
Surface lipids	407	.205*	139	.614*	145	.204	123	−.410*
Total lipids	218	.275*	75	.582*	96	.230	----	----
Protein	----	----	139	−.351*	----	----	----	----
Amylose	407	.302*	----	----	145	.220*	123	.188
Amylopectin	407	−.324*	----	----	145	−.256*	123	−.175
Amylose/amylopectin ratio	407	.303*	----	----	145	.215*	123	.197
Alkali spreading	137	−.568*	44	−.434*	50	−.359*	43	−.412*
Alkali clearing	137	−.566*	44	−.426*	50	−.364*	43	−.397*
Water uptake—77° C	419	−.460*	150	−.398*	147	−.361*	----	----
Water uptake—82° C	420	−.210*	150	−.214*	----	----	----	----
Sediment—77° C	419	−.209*	----	----	147	−.328*	----	----
Sediment—82° C	----	----	----	----	147	−.214*	----	----
Palatability—Appearance	70	−.361*	17	−.715*	----	----	34	−.523*
Palatability—Flavor	70	−.426*	17	−.498	----	----	----	----
Gelatinization temperature	160	.483*	60	.324	63	.461*	37	.390
Heat alteration	197	−.568*	61	−.310	67	−.457*	69	−.463*
Kernel length	422	.199*	152	−.186	147	.189	123	−.183
Kernel width	422	−.253*	----	----	147	−.279*	123	−.280*
L-color (lightness):								
Surface lipids	357	−.394*	108	−.209	127	−.397*	122	−.566*
Total lipids	211	−.264*	----	----	87	−.301*	47	−.495*
Protein	----	----	108	.290*	----	----	122	−.207
Amylose	----	----	108	−.436*	----	----	----	----
Amylopectin	----	----	108	.484*	----	----	----	----
Amylose/amylopectin ratio	----	----	108	−.463*	----	----	----	----
Iodine-blue value	357	−.323*	----	----	127	−.487*	122	−.367*
Alkali spreading	----	----	----	----	----	----	45	.378*
Alkali clearing	----	----	51	.296	----	----	45	.337
Water uptake—77° C	----	----	111	.441*	----	----	121	.180
Water uptake—82° C	361	.298*	111	.525*	128	.247*	122	.323*
Sediment—77° C	360	.281*	111	.428*	128	.185	121	.405*
Sediment—82° C	361	.346*	111	.502*	128	.259*	122	.368*
Palatability—Cohesiveness	85	−.237*	26	.636*	23	.412	----	----
Palatability—Flavor	85	.349*	26	.453	----	----	----	----
Heat alteration	----	----	66	.311*	----	----	----	----

TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*—Continued

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Gelatinization temperature:								
Heat alteration	160	−0.483*	60	−0.324*	63	−0.461*	37	−0.390
Kernel length	181	.366*	71	−.254			39	−.338
Broken kernels	160	.483*	60	.324	63	.461*	37	.390
Surface lipids	175	.236*	66	.324				
Total lipids	123	.241*			52	.313		
Protein	175	.250*						
Amylose/amylopectin ratio	175	.607*	66	.538*	70	.565*	39	.341
Alkali spreading	75	−.795*	30	−.592*	30	−.838*	15	−.942*
Alkali clearing	75	−.787*	30	−.611*	30	−.816*	15	−.938*
Water uptake—77° C	180	−.835*	71	−.733*	71	−.851*	33	−.585*
Water uptake—82° C	181	−.318*	71	−.330*	71	−.237		
Palatability—Cohesiveness	36	.589*						
Palatability—Flavor					12	−.601		
Amylose			66	.524*			39	.324
Amylopectin					70	−.612*		
Heat alteration:								
Kernel length	216	−.501*					71	−.475*
Broken kernels	197	−.568*	61	−.310	67	−.457*	69	−.463*
L-color (lightness)			66	.311*				
Amylose/amylopectin ratio	409	.308*			146	.216*	123	.197
Alkali spreading	153	.809*	53	.477*	56	.852*	44	.894*
Alkali clearing	153	.816*	53	.570*	56	.824*	44	.888*

Water uptake—77° C	215	.846*	72	.820*	73	.771*	70	.699*
Water uptake—82° C	215	.332*	71	.356*	---	---	71	.268
Gelatinization temperature	160	—.483*	60	—.324*	63	—461*	37	—.390
Palatability—Cohesiveness	84	—.531*	---	---	---	---	---	---
Water uptake—77° C.:								
Water uptake—82° C	471	.541*	166	.512*	178	.478*	126	.580*
Sediment—77° C	471	.567*	167	.580*	178	.632*	126	.403*
Sediment—82° C	471	.351*	166	.329*	178	.393*	126	.449*
Palatability—Cohesiveness	86	—.547*	---	---	24	—.815*	---	---
Palatability—Tenderness	86	—.312*	---	---	---	---	---	---
Palatability—Flavor	86	.342	---	---	---	---	---	---
Gelatinization temperature	180	—.835*	71	—.733*	71	—.851*	38	—.585*
Heat alteration	215	.846*	72	.820*	73	.771*	70	.699*
Kernel length	471	—.451*	---	---	---	---	126	.257*
Broken kernels	419	—.460*	150	—.398*	147	—.361*	---	---
L-color (lightness)	---	---	111	.441*	---	---	121	.180
Surface lipids	---	---	156	—.262*	---	---	---	---
Protein	440	—.296*	---	---	---	---	126	—.241*
Amylose starch	440	—.621*	156	—.583*	158	—.447*	126	—.495*
Amylopectin starch	440	.674*	156	.576*	158	.534*	126	.547*
Amylose/amylopectin ratio	440	—.642*	156	—.574*	158	—.487*	126	—.538*
Alkali spreading	155	.797*	55	.688*	56	.813*	44	.645*
Alkali clearing	155	.806*	55	.753*	56	.786*	44	.626*
Sediment—77° C.:								
Sediment—82° C	471	.719*	166	.741*	178	.753*	126	.724*
Palatability—Cohesiveness	86	—.554*	27	—.394	24	—.659*	35	—.544*
Palatability—Tenderness	86	—.250	---	---	---	---	35	—.424
Kernel length	471	—.217*	---	---	---	---	126	.230*
Broken kernels	419	—.209*	---	---	147	—.328*	---	---
L-color (lightness)	360	.281*	111	.428*	128	.185	121	.405*
Amylose/amylopectin ratio	440	.439*	155	.478*	158	—.374*	126	.274*
Iodine-blue value	449	—.108	---	---	159	—.331*	126	—.191
Alkali spreading	155	.458*	55	.300	56	.536*	44	.484*
Alkali clearing	155	.451*	55	.328	56	.495*	44	.475*
Water uptake—77° C	471	.567*	167	.580*	178	.632*	126	.403*
Water uptake—82° C	471	.413*	166	.416*	178	.313*	126	.469*

TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*—Continued

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Water uptake—82° C.:								
Sediment—77° C	471	0.413*	166	0.416*	178	0.313*	126	0.469*
Sediment—82° C	472	.329*	166	.380*	179	.210*	127	.434*
Palatability—Appearance	87	—.232						
Palatability—Cohesiveness	87	—.456*	27	—.398	24	—.645*		
Palatability—Tenderness	87	—.283*			24	—.426		
Gelatinization temperature	181	—.318*	71	—.330*	71	—.237		
Heat alteration	215	.332*	71	.356*			71	.268
Kernel length	472	—.140*					127	.348*
Broken kernels	420	—.210*	150	—.214*				
L-color (lightness)	361	.298*	111	.525*	128	.247*	122	.323*
Surface lipids							127	—.184
Protein	441	—.198*			159	—.260*	127	—.243*
Amylose starch	441	—.268*	155	.233*			127	—.354*
Amylopectin starch	441	.347*	155	.295*	159	.189	127	.401*
Amylose/amylopectin ratio	441	—.299*	155	—.266*			127	—.371*
Iodine-blue value	450	—.272*	163	—.272*	160	—.410*		
Alkali spreading	156	.435*	55	.569*	56	.300	45	.407*
Alkali clearing	156	.417*	55	.548*	56	.285	45	.369
Water uptake—77° C	471	.541*	166	.512*	178	.478*	126	.580*
Sediment—82° C.:								
Palatability—Cohesiveness	87	—.518*	27	—.641*			36	—.585*
Palatability—Tenderness							36	—.346
Kernel length							127	.290*

Broken kernels	---	---	---	---	147	—.214*	---	---
L-color (lightness)	361	.346*	111	.502*	128	.259*	122	.368*
Amylose/amylopectin ratio	441	—.364*	155	—.375*	158	—.365*	127	—.338*
Iodine-blue value	450	—.101	---	---	159	—.216*	127	—.249*
Alkali spreading	156	.276*	---	---	56	.422*	45	.478*
Alkali clearing	156	.243*	---	---	56	.336*	45	.482*
Water uptake—77° C	471	.351*	166	.329*	178	.393*	126	.449*
Water uptake—82° C	472	.329*	166	.380*	179	.210*	127	.434*
Sediment—77° C	471	.719*	166	.741*	178	.753*	126	.724*
Alkali spreading:								
Alkali clearing	156	.966*	55	.936*	56	.963*	45	.977*
Water uptake—77° C	155	.797*	55	.688*	56	.813*	44	.645*
Water uptake—82° C	156	.435*	55	.569*	56	.300	45	.407*
Sediment—77° C	155	.458*	55	.300	56	.536*	44	.484*
Sediment—82° C	156	.276*	---	---	56	.422*	45	.478*
Palatability—Cohesiveness	87	—.418*	---	---	24	—.698*	---	---
Palatability—Flavor	87	.320*	---	---	24	.422	---	---
Gelatinization temperature	75	—.795*	30	—.592*	30	—.838*	15	—.942*
Heat alteration	153	.809*	53	.477*	56	.852*	44	.894*
Kernel length	156	—.392*	---	---	---	---	45	.696*
Broken kernels	137	—.568*	44	—.434*	50	—.359*	43	—.412*
L-color (lightness)	---	---	---	---	---	---	45	.378*
Amylose	152	—.491*	---	---	55	—.471*	45	—.523*
Amylopectin	152	.520*	---	---	55	.525*	45	.544*
Amylose/amylopectin ratio	152	—.507*	---	---	55	—.506*	45	—.546*
Alkali clearing:								
Water uptake—77° C	155	.806*	55	.753*	56	.786*	44	.626*
Water uptake—82° C	156	.417*	55	.548*	56	.285	45	.369
Sediment—77° C	155	.451*	55	.328	56	.495*	44	.475*
Sediment—82° C	156	.243*	---	---	56	.336*	45	.482*
Palatability—Cohesiveness	87	—.435*	---	---	24	—.712*	---	---
Palatability—Tenderness	87	—.234	---	---	---	---	---	---
Palatability—Flavor	87	.339*	---	---	---	---	---	---
Gelatinization temperature	75	—.787*	30	—.611*	30	—.816*	15	—.938*
Heat alteration	153	.816*	53	.570*	56	.824*	44	.888*
Kernel length	156	—.430*	---	---	56	—.278	45	.731*
Broken kernels	137	—.566*	44	—.426*	50	—.364*	43	—.397*

TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*—Continued

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Alkali clearing—Continued								
L-color (lightness)	----	----	51	0. 296	----	----	45	0. 337
Amylose starch	152	−0. 492*	----	----	55	−0. 428*	45	−. 439*
Amylopectin starch	152	. 527*	----	----	55	. 489*	45	. 476*
Amylose/amylopectin ratio	152	−. 511*	----	----	55	−. 467*	45	−. 466*
Iodine-blue value	----	----	----	----	----	----	45	−. 341
Alkali spreading	156	. 966*	55	. 936*	56	. 963*	45	. 977*
Surface lipids:								
Total lipids	240	. 779*	88	. 843*	102	. 677*	49	. 900*
Protein	441	−. 118*	155	−. 277*	----	----	----	----
Amylose/amylopectin ratio	----	----	----	----	158	. 234*	----	----
Water uptake—77° C	----	----	156	−. 262*	----	----	----	----
Water uptake—82° C	----	----	----	----	----	----	127	−. 184
Palatability—Appearance	87	−. 292*	27	−. 848*	----	----	36	. 496*
Palatability—Cohesiveness	----	----	27	−. 606*	----	----	36	. 474*
Palatability—Tenderness	87	. 323*	----	----	----	----	36	. 641*
Palatability—Flavor	87	−. 238	----	----	----	----	----	----
Gelatinization temperature	175	. 236*	66	. 324	----	----	----	----
Kernel length	----	----	155	−. 173	----	----	----	----
Broken kernels	407	. 205*	139	. 614*	145	. 204	123	−. 410*
L-color (lightness)	357	−. 394*	108	−. 209	127	−. 397*	122	. 566*

Total lipids:								
Protein	----	----	88	-.289*	----	----	----	----
Amylose/amylopectin ratio	240	.137	----	----	102	.228	----	----
Palatability—Cohesiveness	----	----	22	-.477	----	----	----	----
Palatability—Tenderness	54	.431*	22	.500	----	----	17	.582
Palatability—Flavor	54	-.300	----	----	----	----	----	----
Gelatinization temperature	123	.241*	----	----	52	.313	----	----
Kernel length	----	----	----	----	103	.235	----	----
Broken kernels	218	.275*	75	.582*	96	.230	----	----
L-color (lightness)	211	-.264*	----	----	87	-.301*	47	-.495*
Surface lipids	240	.779*	88	.843*	102	.677*	49	.900*
Protein:								
Amylose/amylopectin ratio	----	----	155	-.329*	158	-.175	----	----
Water uptake—77° C	440	-.296*	----	----	----	----	126	-.241*
Water uptake—82° C	441	-.198*	----	----	159	-.260*	127	-.243*
Palatability—Cohesiveness	87	.401*	----	----	24	.511	36	.386
Palatability—Flavor	----	----	----	----	24	-.408	----	----
Gelatinization temperature	175	.250*	----	----	----	----	----	----
Kernel length	441	503*	155	.511*	----	----	127	-.280*
Broken kernels	----	----	139	-.351*	----	----	----	----
L-color (lightness)	----	----	108	.290*	----	----	122	-.207
Surface lipids	441	-.118	155	-.277*	----	----	----	----
Total lipids	----	----	88	-.289*	----	----	----	----
Amylose starch:								
Alkali spreading	152	-.491*	----	----	55	-.471*	45	-.523*
Alkali clearing	152	-.492*	----	----	55	-.428*	45	-.439*
Water uptake—77° C	440	-.621*	156	-.583*	158	-.447*	126	-.495*
Water uptake—82° C	441	-.268*	155	-.233*	----	----	127	-.354*
Palatability—Appearance	----	----	----	----	24	-.442	----	----
Palatability—Cohesiveness	87	.386*	----	----	----	----	----	----
Palatability—Flavor	87	-.397*	----	----	24	-.498	----	----
Kernel length	441	.308*	155	-.220*	----	----	127	-.236*
Broken kernels	407	.302*	----	----	145	.220*	123	.188
L-color (lightness)	----	----	108	-.436*	----	----	----	----
Gelatinization temperature	----	----	66	.524*	----	----	39	.324

TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*—Continued

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Amylopectin starch:								
Alkali spreading	152	0.520*	------	------	55	0.525*	45	0.544*
Alkali clearing	152	.527*	------	------	55	.489*	45	.476*
Water uptake—77° C	440	.674*	156	0.576*	158	.534*	126	.547*
Water uptake—82° C	441	.347*	155	.295*	159	.189	127	.401*
Palatability—Cohesiveness	87	—.462*	------	------	------	------	------	------
Palatability—Tenderness	87	—.309*	------	------	------	------	------	------
Palatability—Flavor	87	.423*	------	------	24	.515	------	------
Kernel length	441	—.381*	------	------	------	------	127	.307*
Broken kernels	407	—.324*	------	------	145	—.256*	123	—.175
L-color (lightness)	------	------	108	.484*	------	------	------	------
Gelatinization temperature	------	------	------	------	70	—.612*	------	------
Amylose/amylopectin ratio:								
Iodine-blue value	439	—.263*	154	—.377*	157	—.270*	127	—.174
Alkali spreading	152	—.507*	------	------	55	—.506*	45	—.546*
Alkali clearing	152	—.511*	------	------	55	—.467*	45	—.466*
Water uptake—77° C	440	—.642*	156	—.574*	158	—.487*	126	—.538*
Water uptake—82° C	441	—.299*	155	—.266*	------	------	127	—.371*
Sediment—77° C	440	.439*	155	.478*	158	—.374*	126	.274*
Sediment—82° C	441	—.364*	155	—.375*	158	—.365*	127	—.338*
Palatability—Appearance	------	------	------	------	24	—.421	------	------
Palatability—Cohesiveness	87	.420*	------	------	------	------	------	------
Palatability—Tenderness	87	.233	------	------	------	------	------	------

Palatability—Flavor	87	−.415*	-----	-----	24	−.530*	-----	-----
Gelatinization temperature	175	.607*	66	.538*	70	.565*	39	.341
Heat alteration value	409	.308*	-----	-----	146	.216*	123	.197
Kernel length	441	.326*	155	−.214*	-----	-----	127	−.207*
Broken kernels	407	.303*	-----	-----	145	.215*	123	.197
L-color (lightness)	-----	-----	108	−.463*	-----	-----	-----	-----
Surface lipids	-----	-----	-----	-----	158	.234*	-----	-----
Total lipids	240	.137	-----	-----	102	.228	-----	-----
Protein	-----	-----	155	−.329*	158	−.175	-----	-----
Iodine-blue value:								
Alkali clearing	-----	-----	-----	-----	-----	-----	45	−.341
Sediment—77° C	449	−.108	-----	-----	159	−.331*	126	−.191
Sediment—82° C	450	−.101	-----	-----	159	−.216*	127	−.249*
Palatability—Appearance	-----	-----	-----	-----	23	.524	-----	-----
Palatability—Cohesiveness	-----	-----	27	−.529*	-----	-----	-----	-----
Kernel length	-----	-----	-----	-----	-----	-----	127	−.494*
L-color (lightness)	357	−.323*	-----	-----	127	−.487*	122	−.367*
Amylose/amylopectin ratio	439	−.263*	154	−.377*	157	−.270*	127	−.174
Palatability—Appearance:								
Broken kernels	70	−.361*	17	−.715*	-----	-----	34	−.523*
Water uptake—82° C	87	−.232	-----	-----	-----	-----	-----	-----
Surface lipids	87	−.292*	27	−.848*	-----	-----	36	.496*
Amylose	-----	-----	-----	-----	24	−.442	-----	-----
Amylose/amylopectin ratio	-----	-----	-----	-----	24	−.421	-----	-----
Iodine-blue value	-----	-----	-----	-----	23	.524	-----	-----
Palatability—Cohesiveness:								
Gelatinization temperature	36	.589*	-----	-----	-----	-----	-----	-----
Kernel length	87	.454*	-----	-----	24	.521*	-----	-----
L-color (lightness)	85	−.237	26	−.636*	23	.412	-----	-----
Surface lipids	-----	-----	27	−.606*	-----	-----	36	.474*
Total lipids	-----	-----	22	−.477*	-----	-----	-----	-----
Protein	87	.401*	-----	-----	24	.511	36	.386
Amylose	87	.386*	-----	-----	-----	-----	-----	-----
Amylopectin	87	−.462*	-----	-----	-----	-----	-----	-----
Amylose/amylopectin ratio	87	.420*	-----	-----	-----	-----	-----	-----

TABLE 27.—*Significant correlations for total, long-, medium-, and short-grain rices*—Continued

[All "r" values (correlation coefficients) are significant or highly significant; the highly significant correlation coefficients are marked with asterisks. Samples are classified according to grain length but without regard to country]

Variables	Total		Long-grain		Medium-grain		Short-grain	
	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values	Number of samples	"r" values
Palatability—Cohesiveness—Continued								
Iodine-blue value			27	−0.529*				
Alkali spreading	87	−0.418*			24	−0.698*		
Alkali clearing	87	−.435*			24	−.712*		
Water uptake—77° C	86	−.547*			24	−.815*		
Water uptake—82° C	87	−.456*	27	−.398	24	−.645*		
Sediment—77° C	86	−.554*	27	−.394	24	−.659*	35	−0.544*
Sediment—82° C	87	−.518*	27	−.641*			36	−.585*
Heat alteration	84	−.531*						
Palatability—Tenderness:								
Kernel length	87	.365*						
Surface lipids	87	.323*					36	.641*
Total lipids	54	.431*	22	.500			17	.582
Amylopectin	87	−.309*						
Amylose/amylopectin ratio	87	.233						
Alkali clearing	87	−.234						
Water uptake—77° C	86	−.312*						
Water uptake—82° C	87	−.283*			24	−.426		
Sediment—77° C	86	−.250					35	−.424
Sediment—82° C							36	−.346

Palatability—Flavor:								
Gelatinization temperature	---	---	---	---	---	---	12	−.601
Broken kernels	70	−.426*	17	−.498	---	---	---	---
L-color (lightness)	85	.349*	26	.453	---	---	---	---
Surface lipids	87	−.238	---	---	---	---	---	---
Total lipids	54	−.300	---	---	---	---	---	---
Protein	---	---	---	---	---	---	24	−.408
Amylose	87	−.397*	---	---	---	---	24	−.498
Amylopectin	87	.423*	---	---	---	---	24	.515
Amylose/amylopectin ratio	87	−.415*	---	---	---	---	24	−.530*
Alkali spreading	87	.320	---	---	---	---	24	.422
Alkali clearing	87	.339*	---	---	---	---	---	---
Water uptake—77° C	86	.342*	---	---	---	---	---	---

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