MEASUREMENT OF THE SIZE AND SIZE DISTRIBUTION OF MILLED RICE[1]

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ABSTRACT

Physical dimensions of length, width, and projected area were determined for whole-kernel (head) rice and the three classes of broken kernels as defined by U.S. Standards for Milled Rice. There was a serious overlap of all dimension parameters among various classes of broken kernels separated by current conventional methods. The single physical parameter whch best classified particles into a particular size category is projected area. A study of a commercially available optical instrument for measuring size on the basis of projected area showed that a) the principle of projected area provided a satisfactory method, b) imperfect orientation of the particles presented to the optical unit seriously affected results, and c) the operational speed of the unit was too slow. Design criteria are suggested for an optical sizing unit for milled and brown rice.

One of the important factors in determining the official grade of brown and milled rice (1) is the percentage of whole kernels and the percentage of various classes of broken kernels. Various factors contribute to breakage of rice and its consequent decrease in economic value. It is necessary to accurately determine the amount and class of broken kernels because these quantities contribute to the market value of brown and milled rice.

A number of devices have been developed for classifying products into size categories. Most of the precision devices such as the Coulter Counter[3], sedimentation apparatus and air classifier have been oriented toward the 0.1 to 100 μm particle size range. Sieves, riddles, and indent cylinders have been used in the laboratory and more extensively in commercial processing plants for the separation of particles of various sizes. The shape of the rice kernel, however, has prevented accurate separation by those devices since the major axis can be two to five times that of the minor axis. Even though there is a plane of maximum stability for the rice kernel—*i.e.*, the length-width dimensions parallel to a horizontal surface—the rounded ends tend to allow the kernel to tip over and pass through a sieve. In 1955, Smith (2) developed a device consisting of inclined indent plates which were mechanically vibrated. The device, although used extensively for official grading, has been found to give highly variable results (3) and is now used largely as an aid to the inspector who must make the final analysis by the hand separation method.

Although various and promising electro-optical methods have been studied (4), none has been developed into a practical device suitable for routine inspection of rice.

Kramer (5) and Adair *et al.* (6) have reported length, width, and thickness data for a number of rice varieties grown in the U.S. Their studies do not provide the

[1]The specific mention of trade names or companies is made for identification purposes only and does not imply endorsement by the U.S. Department of Agriculture over other products.

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[3]Coulter, W. H. High speed automatic blood cell counter and cell size analyzer. Unpublished paper presented at the Nat'l. Electronics Conf., Chicago, Ill. (1956).

information necessary for the development of an automated rice-sizing device, since much of the data are for rough rice. Their data indicate that thickness is of little value for designing a sizing device. Official grading, even though largely subjective, uses the length-width ratio as a criterion of size.

The objectives of this study were a) to determine the physical dimensions of whole-kernel milled rice (head rice) and various classes of broken kernels presently used in official grading, b) to determine the relation between certain physical dimensions and weight, and c) to investigate the feasibility of using a commercially available optical instrument to measure size and size distribution of rice.

MATERIALS AND METHODS

Ten samples of each of the three grain types (long, medium, and short) were obtained from the Board of Appeals and Review-Rice (BARR), Agricultural Marketing Service, U.S. Department of Agriculture. The BARR provided official grading data of the size composition, *i.e.*, the percentages of head, second head, screenings, and brewers. The BARR also provided a small subsample of each sample that had been physically separated into the four size categories. Fifteen additional samples of head (whole kernel) rice of the commonly grown varieties were obtained from the Texas A&M University Agricultural Research and Extension Center at Beaumont.

Length, width, projected area, and weight were determined for about 400 particles from each of the four size categories within each of the three grain types. Data were similarly collected from about 100 kernels from each of the 15 variety samples.

The length and width were measured with an electric caliper. The image of the kernel or particle was enlarged about 20 times to increase the precision of measurement, and the projected area was measured with a photoelectric device constructed in this laboratory. An enlarged image of the kernel was projected onto a silicon solar cell, which produced an electrical output inversely proportional to the area of the image. Both the electric caliper and photoelectric device were connected to a digital recording voltmeter to facilitate collection of data. The data were subsequently transferred to perforated paper tape for computer analysis.

The HIAC automatic particle counter (Fig. 1), a High Accuracy Products Corporation Model PC305 SSTA, was evaluated for determining the size and size distribution of rice. This instrument determines size on the basis of projected area. The optical unit contains a collimated regulated light source and a photoelectric sensor. The HIAC gives a digital readout of the number of particles observed in each of five selected size ranges. The instrument was equipped with a special optical unit for relatively large particles (300 to 9000 μm equivalent diameter) and therefore required calibration against a sample of known size distribution.

Rice was allowed to flow "free fall" through the sensing zone. Since the cross-sectional area of rice varies considerably with the plane viewed, it was desirable to orient the particles as they passed through the sensing zone of the optical unit. Several methods were tried, including inclined glass tubes and various V-groove channels. Although none of them was entirely satisfactory, they did improve results adequately. Statistically large samples allowed the errors to be compensating. The measured projected areas are smaller, on the average, than the actual because of imperfect orientation. The error can be accounted for with a correction factor or by simply offsetting the calibration size limits.

The optical unit was modified by the addition of a high-speed air blast separator so that the particles classified into a particular size category could be visually observed. A signal from the digital counting unit was amplified and conditioned for driving a high-speed solenoid valve. Suitable time-delays were incorporated into the reject circuit so that a "reject" particle could be diverted from the main stream (free-fall trajectory) soon after it had passed through the sensing zone. The sorting mechanism, although useful for subjective evaluation of the relative size of particles in a particular category, was too slow for practical use. Three passes were required to separate the rice into the four commonly used size categories because only one sort could be made per pass.

To evaluate the HIAC instrument, subsamples of each of the size categories and grain types previously separated by the BARR were used to determine CAL NOS (calibration numbers). The CAL NOS provided a threshold signal level. Potentiometers for each of the five channels were then adjusted so that the desired size range (projected area) could be counted in one of the channels. Since the BARR had separated the subsamples into four size categories, only four channels of the instrument were used. Channel 1 was adjusted to count, on the average, most of the particles designated as brewers, channel 2 for screenings, and so on. After the CAL NOS had been determined, a 40-g sample from the bulk

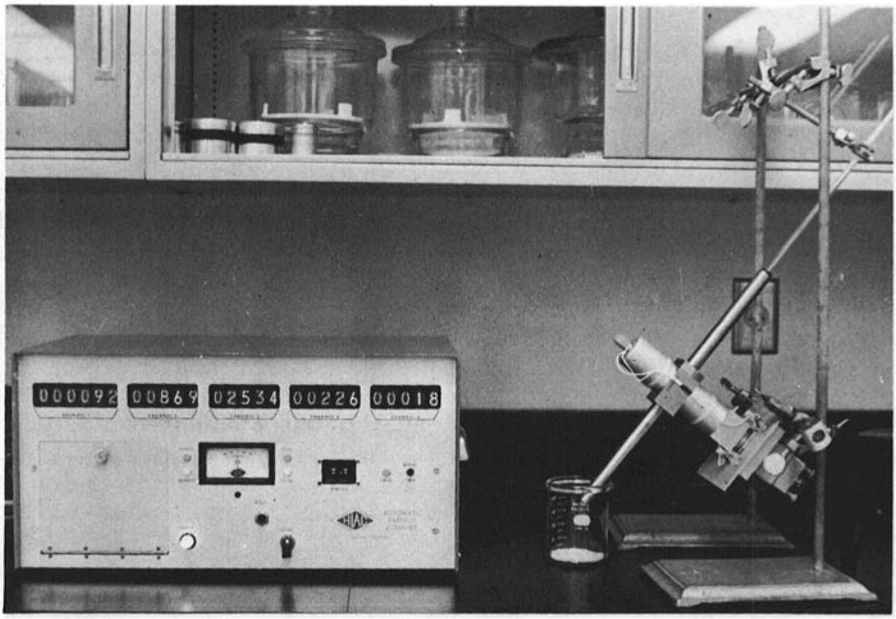

Fig. 1. HIAC automatic particle counter.

was analyzed. Slight adjustments were made in the CAL NOS to yield analyses that closely approximated the results given by the BARR. Counts by the HIAC were converted to a weight basis, and subsequently to percentage by weight from the weight per kernel data obtained in objective b of this study. The 40-g sample was then analyzed five times for statistical analyses.

RESULTS AND DISCUSSION

Physical Dimensions of Milled Rice

Frequency tables for a) length, b) length-width ratio, and c) projected area for each of the four size categories and each of the three grain types are shown in Tables I, II, and III, respectively. Apparently, no single parameter would classify particles into the size categories presently used in official grading. The lack of a high degree of correspondence can be primarily attributed to the subjective method currently used. Official inspectors base their decisions on the length-width ratio for each kernel under consideration. For example, a particle slightly less than one-half the length of the whole kernel would be classified as screenings. If the particle came from a fully mature, plump kernel, it could be larger in length, width, and projected area than a whole, slender, immature kernel. The present grading system would classify the latter as a whole kernel. Simple objective methods cannot make that distinction. More complicated devices such as pattern-recognition devices (7) could do this but may be prohibitive in cost and complexity.

Another explanation for the lack of correspondence is the variation due to

TABLE I
Frequency of Particles Observed in a Given Length Interval of Four Size Categories[a] in Each of Long, Medium, and Short Grain Types

Length Interval mm	Long				Medium				Short			
	1	2	3	4	1	2	3	4	1	2	3	4
<0.53									1			
0.53–1.07	7			1	1				43	1		
1.08–1.60	96	52	4		30	12			198	23	3	
1.61–2.13	103	279	31		129	118	12		218	181	9	
2.14–2.67	28	167	150	1	81	182	90	1	31	173	170	2
2.68–3.20		12	206		9	85	167	2		34	190	3
3.21–3.73			80	2		3	90	23			41	9
3.74–4.27			39	4			28	45			4	22
4.28–4.80			21	22			8	58				222
4.81–5.33			1	88				113				142
5.34–5.87				153				162				6
5.88–6.40			2	120				19				
6.41–6.93				85								1
6.94–7.47				18								
7.48–8.00				3								
>8.00				1								

[a]Categories separated by present conventional methods were 1) brewers, 2) screenings, 3) second heads, and 4) head.

TABLE II
Frequency of Particles Observed in a Given Length-Width Ratio Interval of Four Size Categories[a] in Each of Long, Medium, and Short Grain Types

Length-Width Interval	Long				Medium				Short			
	1	2	3	4	1	2	3	4	1	2	3	4
<0.4												
0.4–0.69	26	29	10	0	6	18	2		63	52	5	
0.7–0.99	78	210	16		68	136	51		205	198	155	3
1.0–1.29	95	216	104		128	158	180	2	157	108	222	9
1.3–1.59	25	55	201	1	39	73	90	24	46	49	25	139
1.6–1.89	10		131	4	8	15	45	65	17	5	9	225
1.9–2.19			51	31	1		21	203	1		1	26
2.2–2.49			14	26			3	125				3
2.5–2.79			3	73				3				2
2.8–3.09			1	169				1				
3.1–3.39			1	137								
3.4–3.69				44								
3.7–3.99				11								
4.0–4.29				1								
4.3–4.59			1	1								
4.6–4.89												
4.9–5.19			1									
>5.20												

[a]Categories separated by present conventional methods were 1) brewers, 2) screenings, 3) second heads, and 4) head.

TABLE III
Frequency of Particles Observed in a Given Area Interval of Four Size Categories[a] in Each of Long, Medium, and Short Grain Types

Area mm^2	Long				Medium				Short			
	1	2	3	4	1	2	3	4	1	2	3	4
< 18.3	5				2	3						
18.3– 27.5	51	2			29	2			76	1	1	
27.6– 36.6	110	79	9		137	42	1	1	198	18	4	
36.7– 45.8	67	283	108		82	194	15	1	177	170	17	
45.9– 55.0	1	103	201			129	84	1	30	165	50	
55.1– 64.1		23	144	2		27	129	8	6	55	116	1
64.2– 73.3		12	51	24		2	114	17		2	132	1
73.4– 82.5		5	14	76		1	39	51		1	67	14
82.6– 91.6		2	5	110			11	62			23	10
91.7–100.8		1	1	123			1	73			6	32
100.9–109.9			1	98				114			1	79
110.0–119.1				49				81				129
119.2–128.3				13				13				107
128.4–137.4				2				1				28
137.5–146.6												5
>146.6				1								

[a]Categories separated by present conventional methods were 1) brewers, 2) screenings, 3) second heads, and 4) head.

varietal differences. Table IV indicates that physical dimension varies considerably within a single grain type. No attempt was made to identify the varieties. The samples measured included varieties representative of a grain type.

Head rice could be separated on the basis of length alone (Table I). There was little overlap between the length of head rice and lengths of the particles of the other size categories. However, there was material overlap among the lengths of the three categories of broken kernels of all three grain types. Inspection of the length-width ratio and projected area parameters of head rice (Tables II and III) led to similar conclusions. The length-width ratio appeared to be slightly better and projected area somewhat better than length for classifying the three categories of broken kernels of all three grain types. When all grain types were combined and analyzed statistically, the correlation of the log of the projected area with size ($r = 0.881$) was higher than that with either length ($r = 0.815$) or length-width ratio ($r = 0.676$).

Regression analyses of weight data (Table V) yielded correlation coefficients of 0.966, 0.966, and 0.989 for long, medium, and short grain types, respectively, when the log of numbers was compared to the size designations. It appears that separate conversion factors would be necessary for the three grain types, but this should present no serious problems except when grain types are mixed. We conclude, however, that numbers of particles could be converted to weight with sufficient accuracy for official grading by present standards (1).

A summary of the data for commonly grown U.S. varieties shows the expected range in physical dimensions (Table IV). Such data could vary with area of growth, cultural practice, and weather conditions.

TABLE IV
Mean Dimensions of Common Varieties of Milled Head Rice

Variety		Grain Type	Width mm	Length mm	Projected Area mm^2
Bonnet 73		Long	1.66	4.94	8.97
Dawn		Long	2.04	6.66	11.61
Starbonnet		Long	1.91	6.22	10.13
Bluebelle		Long	2.14	6.65	12.07
Belle Patna		Long	1.74	5.47	10.39
Labelle		Long	1.70	5.31	9.42
	Average		1.86	5.87	10.43
Saturn		Medium	2.61	5.40	11.55
CS-M3		Medium	2.19	4.47	10.97
Norte		Medium	2.60	4.90	11.22
Nava 66		Medium	2.28	4.81	11.74
Vista		Medium	2.09	4.61	10.58
Nato		Medium	2.12	4.48	10.65
	Average		2.31	4.78	11.12
Caloro		Short	2.88	4.92	11.68
Colusa		Short	2.46	4.08	11.54
CS-54		Short	2.75	4.64	10.58
	Average		2.70	4.55	11.27

Automatic Particle Counter

Analyses of the data (Table VI) obtained with the HIAC instrument for two samples indicate that this instrument, with modifications, would probably be acceptable for size analysis in official grading of rice. Analysis of variance showed that replications did not differ significantly and that standard deviations were relatively low.

GENERAL DISCUSSION

The most apparent finding of this study is that present subjective methods of grading rice for size and size distribution would be difficult, if not impossible, to duplicate by an automated objective method. It appears that more definitive size designations based on one or more physical dimensions are necessary. Despite present inadequacies, an automated method based on projected area offers a

TABLE V
Mean Particle Weight (mg)

Grain Type	Size Designation[a] 1	2	3	4
Long	2.46	3.75	6.40	13.95
Medium	3.13	5.16	8.23	15.65
Short	2.25	5.24	10.06	20.18

[a]Categories separated by present conventional methods were 1) brewers, 2) screenings, 3) second heads, and 4) head.

TABLE VI
Summary of Size Analyses Obtained with an Automatic Particle Counter[a]

Size Designation	Replication 1	2	3	4	5	Mean	Standard Deviation	Official Analysis (BARR)
			Long Grain Type					
Brewers	0.3	0.4	0.4	0.5	0.4	0.40	0.06	0.3
Screenings	1.4	1.8	1.7	1.9	1.5	1.66	0.19	1.9
Second heads	17.1	16.9	16.8	16.5	17.1	16.88	0.22	17.9
Head	81.2	80.9	81.1	81.1	81.0	81.06	0.10	79.9
			Medium Grain Type					
Brewers	0.8	0.8	0.6	0.9	0.5	0.72	0.15	0.6
Screenings	3.2	3.5	3.3	3.5	3.3	3.36	0.12	3.2
Second heads	16.1	16.2	15.8	16.2	15.8	16.02	0.18	15.7
Head	79.9	79.5	80.3	79.4	80.4	79.90	0.40	80.4

[a]All data reported in per cent.

possible solution. The data collected with the modified HIAC are promising. Further modification of the optical unit to permit more positive orientation of the particles would reduce error to a more acceptable level. A positive means of controlling the rate of travel of the particles through the sensing zone also would improve results. Tests showed that the instrument tended to classify more particles in the smaller size ranges as the flow rate increased. The manufacturer has recognized this problem and has redesigned the circuits to obtain better light level control. We have not tested this new model instrument.

From this study we conclude that: a) there is a serious overlap in physical dimensions of milled rice in the four size categories, b) the number of particles can be converted to a weight basis if the grain type is known; this would eliminate the need for physical sorting and would expedite analyses, c) of the parameters tested, projected area appears to be the best and could be easily implemented in an automated device, and d) the HIAC automatic particle counter in its present form is not suitable for routine measurement of rice; a new optical unit and particle handling mechanism are needed. Also, it might be possible to simplify the electronic counting unit to reduce the cost of the present unit.

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