The Impact of Fissured Rice on Mill Yields[1]

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ABSTRACT

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Fissured kernels in rough rice generally break when milled. Because milling with the least amount of broken rice is a universal goal, experiments were conducted to investigate the effect of known amounts of fissured kernels in rough rice on kernel breakage during shelling and milling. The reduction in whole-kernel yield was dependent on the rice lot tested and the percent of fissured kernels in the rough rice. Fissured kernel levels as low as 10% caused significant reduction in whole-kernel yields of three of the four rice lots tested. Rough rice with fissured kernels in excess of 10% resulted in very low whole-kernel yields. When lots with no fissured kernels were tested, one lot produced whole-kernel yields 10 percentage points lower than the three other lots tested. This trend was attributed to varietal difference and preexisting weak conditions. Linear regression models relating percent fissured kernels in the rough rice to the whole kernel yield, brokens and fissured whole grain in whole kernels and broken rice are presented. These models can be used by rice processors to selected lots of rice to produce milled rice of the desired end quality.

Farmers all over the world have increased the production of rice by adopting modern technology and efficient management techniques. However, quality and quantity losses still occur at the pre- and postharvest phases, where many factors influence the ultimate quality of the grain. Internal cracking is an important factor affecting rice grain quality. According to Kunze and Hall (1965), from a processor's point of view, a rice grain with two or three cross-sectional cracks has lost its commercial value.

Because rice is hygroscopic in nature, changes in the environment cause rice grains to absorb or desorb moisture, which sometimes leads to formation of cracks or fissures. Sharma and Kunze (1982) defined "fissure" as the large internal fracture usually found to be perpendicular to the long axis of the grain. It has long been known that fissured kernels of rice usually break in the milling process. Broken kernels have a considerably lower commercial value than whole, unbroken kernels; therefore, rice processors strive to produce milled rice with the least amount of broken rice.

The causes of rice grain breakage have been classified as those due to the properties of the grains and those due to the conditions under which the grain is milled (Spadaro et al 1980). The properties of grains are strongly influenced by variety, moisture content, and the conditions to which the grains are subjected. Foremost among the causes for grain breakage are the fissures present in the rice when it enters the mill. Fissuring of rice has thus received much attention by researchers, but the trade in general has not considered the presence of fissured whole kernels important. Hence information relating fissured grains in specific lots of rough rice to mill yields would be useful to the processing industry. This study is an attempt to evaluate rice breakage as affected by rice lots and fissured kernels present in rough rice.

Nguyen and Kunze (1984) studied the fissures in rough rice resulting from drying and postdrying treatments and reported that the breakage strength of rough rice was inversely proportional to the percentage of fissured grain at the end of any storage period after drying. Indudhara Swamy and Bhattacharya (1971) studied the breakage of rice during milling and concluded that grain breakage resulted primarily from grain defects, such as fissures. These authors noted that the number of broken grains after milling rarely exceeded the number of defective grains before milling.

The objective of this study was to determine the effects of fissured kernels and rice lot on rice breakage during the milling process, and to develop their regression models.

MATERIALS AND METHODS

Four long-grain rice lots (Lemont, Labelle, Tebonnet, and Newbonnet varieties) from the 1986 crop from Crowley, LA, were used in the study. The rice was cleaned to remove immature kernels and foreign material. The moisture content was then determined for each lot using the oven method (130°C for 16 hr).

To develop artificial fissures in the rough rice, 200 g of cleaned rice for each lot in duplicate was soaked in tap water (at 24°C) for 5 hr so that all the kernels developed fissures (the 5-hr period was determined in a separate pilot investigation). At the end of the soaking period, the water was drained and the samples dried on mesh trays in the laboratory. The period of drying was such that the weight of the grain was brought down to nearly the original weight of 200 g. These samples were then inspected for fissures using a fiber-optic light arrangement. The fissured rice samples were then sealed in plastic bags.

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The bulk of the rice for each lot from which the soaked samples had been drawn was then thoroughly mixed, and another 200-g sample was drawn. The fissured kernels from these 200-g samples were separated and weighed. The results of these determinations were then used as the percentage of fissured kernels initially present in the rough rice lot. With this information, 150-g samples in two replications were prepared with known amounts of fissured kernels (ranging from 0 to 30%). The artificially fissured kernels were used as the source of fissured kernels in preparing the above samples. A 150-g control sample with the initial amount of fissured kernels was also analyzed for each lot.

Each sample was then processed in an identical manner using a McGill sheller and a McGill no. 2 miller. All procedures and machine settings were in accordance with U.S. Department of Agriculture procedures outlined in the Rice Grading and Inspection Handbook (USDA 1976). At the end of the milling stage, the milled rice was collected and allowed to cool for 10 min before manual separation of brokens from the whole kernels. The whole kernels were then inspected, and those with fissures were separated. The weights of the brokens, whole kernels, and fissured whole kernels were recorded.

The statistical design utilized in analyzing the data for the study

TABLE I
Summary of Treatments and Results[a]

Treatment No.	Fissured Kernels in Rough Rice (%)	Milled Rice[b] (%)	Broken Kernels[b] (%)	Whole Kernels[b] (%)	Nonfissured Whole Kernels[c] (%)	Fissured Grain in Whole Kernels[c] (%)	Brokens + Fissured Grain in Whole Kernels (%)
Lemont							
01	C[d]	71.30	16.08	55.26	47.75	7.70	23.78
02	0	71.78	14.15	58.57	58.26	0.31	14.46
03	5	71.51	17.94	53.92	51.59	2.33	20.27
04	10	71.68	22.25	49.44	45.31	4.13	26.38
05	15	71.61	25.62	46.00	42.69	3.31	28.93
06	20	71.71	27.38	44.28	39.74	4.54	31.92
07	25	71.32	32.31	39.01	36.39	2.62	34.93
08	30	71.54	33.17	38.69	34.74	3.95	37.12
Labelle							
09	C[d]	70.96	4.48	66.38	66.22	0.16	4.64
10	0	71.19	3.79	67.40	67.31	0.09	3.88
11	5	71.22	6.75	64.38	61.87	2.52	9.27
12	10	71.16	6.56	64.43	58.65	5.78	12.34
13	15	71.38	13.85	57.49	54.81	2.68	16.53
14	20	72.17	18.99	53.03	49.38	3.65	22.64
15	25	71.47	22.53	48.84	43.89	4.95	27.48
16	30	72..14	22.43	45.21	30.01	15.20	37.63
Tebonnet							
17	C[d]	71.19	6.13	65.06	64.76	0.30	6.43
18	0	73.11	4.89	68.22	68.19	0.03	4.92
19	5	71.96	12.50	59.90	59.17	0.73	13.23
20	10	72.31	13.25	59.01	57.01	2.00	15.25
21	15	71.63	21.39	50.25	48.80	1.45	22.84
22	20	71.42	22.07	49.35	47.72	1.63	23.70
23	25	71.45	25.63	45.93	44.35	1.57	27.20
24	30	71.62	25.72	45.90	41.45	4.45	30.17
Newbonnet							
25	C[d]	71.90	5.87	66.05	65.56	0.49	6.36
26	0	72.22	3.80	68.46	68.43	0.02	3.82
27	5	71.67	8.87	62.31	61.41	0.90	9.77
28	10	71.23	11.06	60.34	57.89	2.45	13.51
29	15	70.76	13.38	58.04	52.62	5.42	18.80
30	20	72.12	17.39	54.73	48.86	5.87	23.26
31	25	71.16	18.68	52.48	44.70	7.78	26.46
32	30	71.75	22.12	49.63	39.43	10.20	32.32

[a] Data are averaged over the two replications.
[b] Expressed as percentage of rough rice.
[c] Expressed as percentage of whole kernels.
[d] Control samples: Lemont C = 4.24%; Labelle C = 2.73%; Tebonnet C = 4.04%; Newbonnet C = 3.44%.

TABLE II
Analysis of Variance for Dependent Variables

		Mean Squares					
Source	df	Milled Rice	Broken Rice	Whole Kernels	Nonfissured Whole Kernels	Fissured Grain in Whole Kernels	Brokens + Fissured Grain in Whole Kernels
Fissured[a]	6	0.6666*[b]	427.9664**	449.3776**	203.4060**	53.7009**	753.4674**
Rice lot	3	0.5900	347.9052**	350.3316**	308.3932**	27.2173**	275.4686**
Fissured × rice lot	18	0.3800	5.4172**	5.5635**	26.9359*	9.8755**	12.4377**

[a] Fissured kernel percent in rough rice.
[b] * $P < 0.05$, ** $P < 0.01$.

was a randomized block design with a factorial arrangement of treatments. There were a total of 32 treatments with two replications yielding 64 treatment combinations.

RESULTS AND DISCUSSION

For discussion purposes, each lot is referenced by its varietal name. The averaged data and particulars of the treatments are presented in Table I. Statistical analyses of variance and Pearson correlation coefficients for the dependent variables are given in Tables II and III, respectively. The linear regression models relating the percent fissured grains in rough rice to the whole kernel yield, brokens, fissured whole kernels, and broken rice are shown in Table IV.

The general trends for whole-kernel yield, broken kernels, and fissured unbroken grains in the whole-kernel fraction, the nonfissured whole kernels, and the fissured whole kernels are illustrated in Figures 1 through 5. At the 0% level of fissures in the rough rice, the whole-kernel yield for the Lemont lot was almost 10% lower than for any of the other three lots. However, increasing the fissured kernels in the rough rice to 30% decreased the whole-kernel yield by an average of 20%. This reduction in the whole-

TABLE III
Pearson Correlation Coefficients for Dependent Variables

Variable	Variety	Milled Rice	Broken Rice	Whole Kernels	Nonfissured Whole Kernels	Fissured Grain in Whole Kernels	Brokens + Fissured Grain in Whole Kernels
Milled rice	Lemont	1.00000	−0.40950	0.46733	0.60288	−0.64707	−0.56083
	Labelle	1.00000	0.80750*[a]	−0.79009*	−0.79620*	0.72106*	0.81598
	Tebonnet	1.00000	−0.45408	−0.50651	0.49716	−0.29050	−0.44119
	Newbonnet	1.00000	−0.29081	0.33356	0.30700	−0.31510	−0.29975
Broken rice	Lemont		1.00000	−0.99752**	−0.95128**	0.03829	0.96252*
	Labelle		1.00000	−0.99953**	−0.97141**	0.77535*	0.96550*
	Tebonnet		1.00000	−0.99819**	−0.96629**	0.74455*	0.99230*
	Newbonnet		1.00000	−0.99822**	−0.99553**	0.97609**	0.97609*
Whole kernels	Lemont			1.0000	0.96639*	−0.09279	−0.97461*
	Labelle			1.0000	0.96912**	−0.76868*	−0.96251*
	Tebonnet			1.0000	0.96937**	−0.73764*	−0.98948*
	Newbonnet			1.0000	0.99239**	−0.97020**	−0.99346*
Nonfissured whole kernels	Lemont				1.00000	−0.33750	−0.99724*
	Labelle				1.00000	−0.89325**	−0.99358*
	Tebonnet				1.00000	−0.58625**	−0.93221*
	Newbonnet				1.00000	−0.98416**	−0.99689*
Fissured grain in whole kernels	Lemont					1.00000	0.30768
	Labelle					1.00000	0.90376*
	Tebonnet					1.00000	0.82067*
	Newbonnet					1.00000	0.99016*
Brokens + fissured grain in whole kernels	Lemont						1.00000
	Labelle						1.00000
	Tebonnet						1.00000
	Newbonnet						1.00000

[a]* $P<0.05$, ** $P<0.01$.

TABLE IV
Linear Models Relating Percentage of Fissures in Rough Rice to Whole Kernel Yield and Breakage

Lot	Linear Models[a]	Regression Correlation
Lemont		
Whole kernel yield	HRICE = (−0.69407) × fiss. + 57.68326	$R^2 = 0.9724$
Brokens + fissured grain in whole kernels	BRFG = (0.68297) × fiss. + 17.95961	$R^2 = 0.9381$
Broken rice	BRICE = (0.66864) × fiss. + 14.48095	$R^2 = 0.9799$
Labelle		
Whole kernel yield	HRICE = (−0.72365) × fiss. + 68.44988	$R^2 = 0.9649$
Brokens + fissured grain in whole kernels	BRFG = (1.11964) × fiss. + 2.15504	$R^2 = 0.9681$
Broken rice	BRICE = (0.75823) × fiss. + 2.46818	$R^2 = 0.9638$
Tebonnet		
Whole kernel yield	HRICE = (−0.77613) × fiss. + 65.97041	$R^2 = 0.9210$
Brokens + fissured grain in whole kernels	BRFG = (0.87502) × fiss. + 6.18155	$R^2 = 0.9552$
Broken rice	BRICE = (0.74782) × fiss. + 6.25398	$R^2 = 0.9214$
Newbonnet		
Whole kernel yield	HRICE = (−0.60030) × fiss. + 67.14214	$R^2 = 0.9760$
Brokens + fissured grain in whole kernels	BRFG = (0.93287) × fiss. + 4.11732	$R^2 = 0.9948$
Broken rice	BRICE = (0.59046) × fiss. + 4.62699	$R^2 = 0.9843$

[a]HRICE = whole kernel yield, BRFG = broken kernels + fissured grain in whole kernels, BRICE = broken rice, fiss. = fissured grains in rough rice.

kernel yield was approximately the same in all varieties. The higher breakage shown by the samples of Lemont with 0% fissures in the rough rice could be attributed to several causes including variety, previous history of the grain, variation of kernel thickness in the lot, and the inability to detect all weak or potentially weak kernels through the observation of fissured kernels in the rough rice. Srinivas et al (1978), who studied crack formation in rice, noted that although crack formation is an inherent varietal characteristic of the grain, it can be modified greatly by preformed stresses developed in the field. Thus it seems that variety and previous history, such as maturation differences, have a combined influence on breakage in the milling process. The percentage of fissured kernels in the control samples is an indication of the inherent ability to resist the forces encountered in a mill or lack of it. The rough rice samples of the Lemont lot had the highest amount of fissured kernels in the control (4.24%) and recorded the highest breakage of 14.15% when samples at the 0% fissures in rough rice were milled. The Labelle lot, on the other hand, was found to have the lowest amount (2.73%) of naturally fissured kernels in the control samples. When rough rice samples of the Labelle lot with 0% fissured kernels were milled, the resulting breakage was found to be the lowest (3.79%) among the four lots tested. The inability of the experimental technique to completely identify fissured grains in the rough rice samples may be one of the causes of the "residual" breakage seen at the 0% fissure level (Table I). Kunze, (1979) reasoned that smaller fissures at either end of a rice kernel are difficult to detect using a light beam because the opaque rice hull diffuses the light over the entire grain, and the kernel inside responds only to the light which has been transmitted through the hull. Again, the low percentage of fissured milled rice kernels among the whole kernels of a sample (0.02–0.31%, Table I) from the 0% fissured groups indicated that the residual breakage was due to the lower accuracy of fissure detection in rough rice combined with other effects. Hence the higher residual breakage of 14% was due to an inherent weakness of the grains in the Lemont lot, whereas the three other varieties showed a residual breakage of about 4% for the groups with 0% fissured kernels in the rough rice (Table I).

The analysis of variance (Table II) indicated that whole-kernel yield was significantly associated with both percent fissured kernels in rough rice and rice lot. However, since there was a significant interaction of these two factors, only the overall trends are reported. The reduction in head yield occurred in a linear fashion as the percentage of fissured kernels in the rough rice

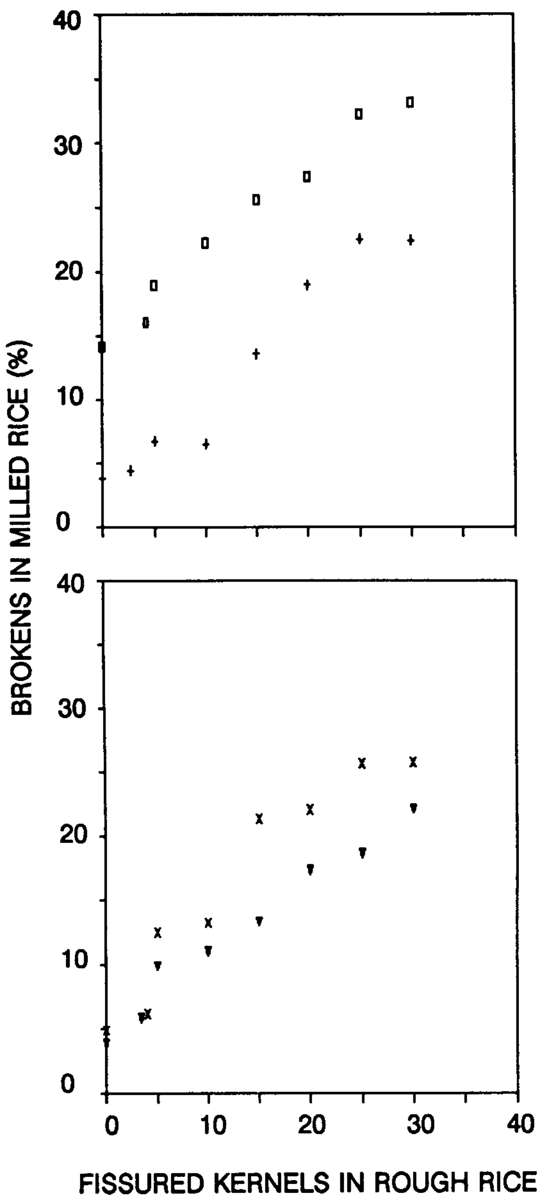

Fig. 1. Variation of breakage in milling (percent brokens based on rough rice) with fissured kernels in rough rice: Lemont (□), Labelle (+), Tebonnet (x), Newbonnet (▽).

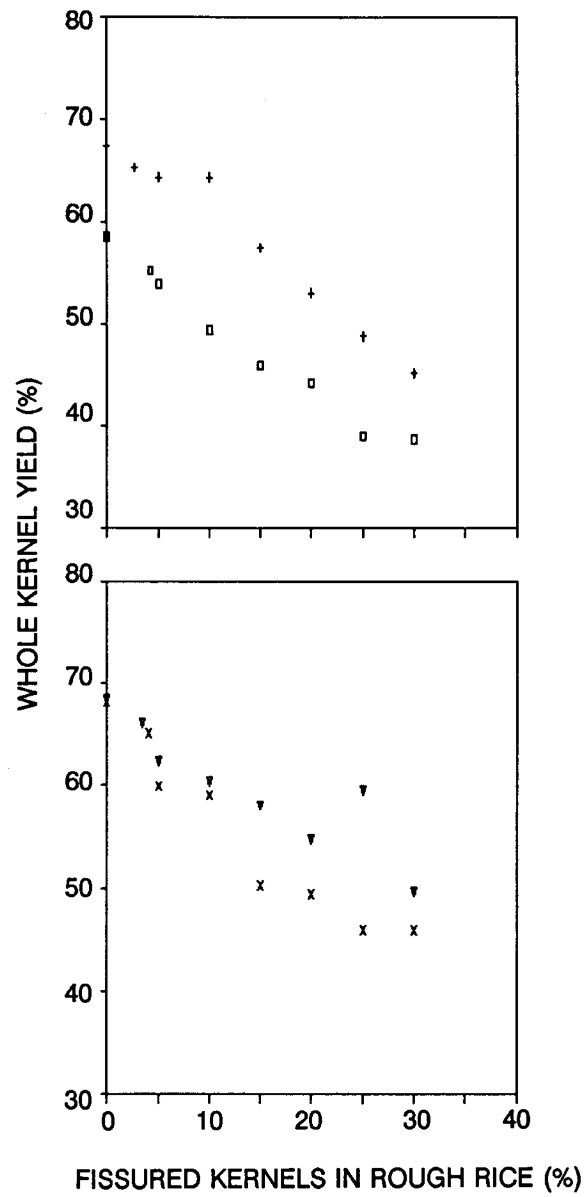

Fig. 2. Variation of whole-kernel yield based on rough rice) with fissured kernels in rough rice: Lemont (□), Labelle (+), Tebonnet (x), Newbonnet (▽).

increased (Fig. 2). The reduction in whole-kernel yield when the percentage of fissured kernels in rough rice increased from 0 to 10, 20, and 30%, respectively, is shown in column D of Table V. The control samples of the rice lots tested had initial amounts of fissured kernels ranging from 2.73% for the Labelle lot to 4.24% for the Lemont lot. On the assumption that these values are typical for rough rice purchased by processors, the reduction in whole-kernel yield, even at the 10% level of fissured grains in the rough rice, is significant (Table V). All lots tested except Labelle showed a whole-kernel yield reduction of 8 to 9%. The Labelle lot showed a reduction of 2.94% and was the lowest among the lots tested. At the 20 and 30% levels of fissures in the rough rice, the reduction in whole-kernel yield, although fairly consistent among the lots tested, appeared to be very high. Therefore, the presence of fissured kernels in rough rice indicated a strong influence in considerably reducing the whole-kernel yields and hence the market value of the lots tested.

Based on the assumption that most fissured kernels in rough rice would tend to break during shelling and milling, column C of Table V was prepared to analyze the effect of the rice lot and percentage of fissured kernels in rough rice. The results showed that both the rice lot and the percentage of fissured kernels in the rough rice had an effect on how many of the fissured kernels broke in the shelling and milling stages. At the 10% level of fissured grains in rough rice, approximately 50% of the fissured kernels in the Lemont and Labelle lots broke, and over 75% of those in the Tebonnet and Newbonnet lots broke. At the 20 and 30% levels of fissured kernels in the rough rice, the results were mixed, the only singularity being the case of Labelle at the 30% level of fissured grains in rough rice (column B, Table V). Although it is safe to assume that a fissured kernel is expected to break in the normal processing steps, the varietal influence and the growing and handling conditions could play a significant part in the strength characteristics. The method of preparation of the fissured kernels for the experiments, although fixed for all varieties, could have had an influence on the strength properties due to the fact that the absorption and desorption rates of water are different for the varieties tested.

Fissured kernels in whole-kernel milled rice, although not specified in the grade requirements of the U. S. standards for milled rice, could lower the overall quality for many reasons. Breakage susceptibility is increased and the fissured kernels are more susceptible to microbial and insect attack. Analysis of variance indicated that the percentage of fissured grains in the rough rice and the rice lot factors were significantly related to the percentage of fissured whole kernels in the milled rice

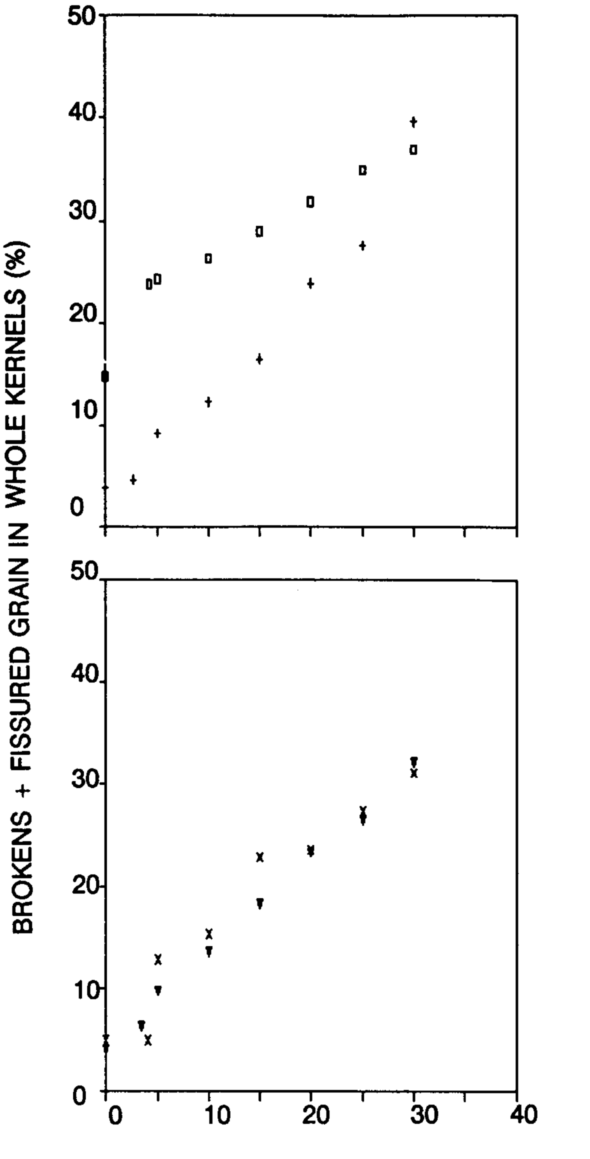

Fig. 3. Variation of broken kernels (based on rough rice) + fissured grain in whole kernels (based on rough rice) with fissured kernels in rough rice: Lemont (□), Labelle (+), Tebonnet (x), Newbonnet (∇).

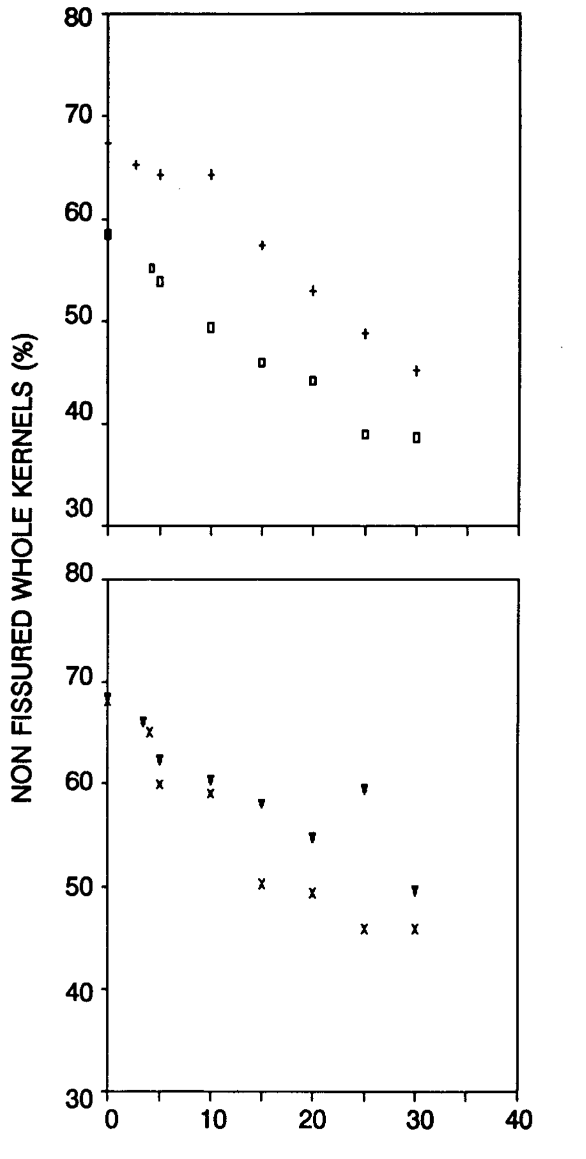

Fig. 4. Variation of the nonfissured whole kernels (based on rough rice) with fissured kernels in rough rice: Lemont (□), Labelle (+), Tebonnet (x), Newbonnet (∇).

(Table II). The behavior of fissured whole kernels in milled rice with respect to the fissures in rough rice is illustrated in Figure 5. All the rice lots tested except Lemont showed an increasing trend as the percentage of fissured grains in the rough rice was increased, with Newbonnet indicating a fairly linear increase. It was also found that the fissured whole grains showed a high negative correlation with whole-kernel rice for the Newbonnet lot (Table III). These results are indicative of the inherent strength of the Newbonnet lot both in the control samples as well as when 30% fissured kernels were present in the rough rice. This is supported by the fact that at the 30% level of fissured grains in the rough rice samples, the Newbonnet lot showed the least breakage (22.12%, Table I). Another point of interest is the high value for for fissured kernels in whole-kernel milled rice in the Lemont control samples, and its apparent independence of the percent of fissured whole kernels in the rough rice as indicated in Figure 5 and the low correlation coefficient with respect to the whole-kernel yield in Table III.

The foregoing comments therefore point to the fact that the fissured kernels in milled whole-kernel rice are highly lot dependent. During the experiments, it was observed that bran removal, which is a friction process, resulted in an average temperature rise of over 15°C above ambient. This increase in grain temperature combined with subsequent cooling could cause a moisture exchange between the rice kernels and the atmosphere resulting in the development of fissures, as indicated by the last column in Table I. Since it is nearly impossible to keep track of an initially fissured kernel throughout the milling process, the number of fissured kernels in the whole-kernel milled rice would be a poor indicator of grain kernel quality.

Linear regression models relating the whole-kernel yield, broken rice, and the sum of brokens plus fissured whole grains, respectively, with the amount of fissured grains in rough rice are illustrated in Table V. Linear models were determined to be suitable in the useful range of applicability for practical use. For the degree of bran removal performed in the study, the whole-kernel yield ranged from a low of 38.69% to a maximum of 68.46%. This range is considered wide enough for a processor to derive useful information on breakage for the lots treated in this study. It is more significant, however, to note that reduction in whole-kernel yield could be as much as 22.32% (in the case of Tebonnet, Table I) when the percentage of fissures in the rough rice was 30%. The economic advantage of knowing beforehand the potential reduction in whole-kernel yield could be an important application of these models. Again, prior knowledge of the fissured grains in rough rice could be used in conjunction with models such as those presented in this study to fine tune processing operations to produce a desired end quality of milled rice.

CONCLUSIONS

The presence of fissured kernels in the rough rice had a strong influence on the reduction of whole-kernel yields and hence the market value of the lots tested in the study.

The reduction in whole-kernel yield was dependent on both the rice lot and the percentage of fissured kernels present in the rough rice. This reduction was found to occur in a nearly linear fashion with the increase in the percentage of fissured kernels in the rough rice.

At the 10% level of fissured grains in the rough rice, a significant reduction (8–9%) in whole-kernel yield was observed in Lemont, Tebonnet, and Newbonnet lots, whereas the Labelle lot reduction was only 2.94%. The reduction in whole-kernel yield at the higher (>10%) levels of fissured kernels in the rough rice was high.

At the 0% level of fissured grains in rough rice, the Lemont lot had whole-kernel yields nearly 10% lower than the other lots tested. This behavior was attributed to a combination of varietal factors and a preexisting weak condition that did not manifest itself as fissured grains in the rough rice.

The amount of fissured kernels in the rough rice that broke during milling was highly dependent on the rice lot as well as the percentage of fissured kernels in the rough rice.

The presence of fissured whole kernels in the milled whole-kernel fraction was influenced by the percentage of fissured kernels in the rough rice only in the case of the Newbonnet lot. The fissured whole kernels in milled rice were found to be an unsuitable indicator of ultimate grain quality.

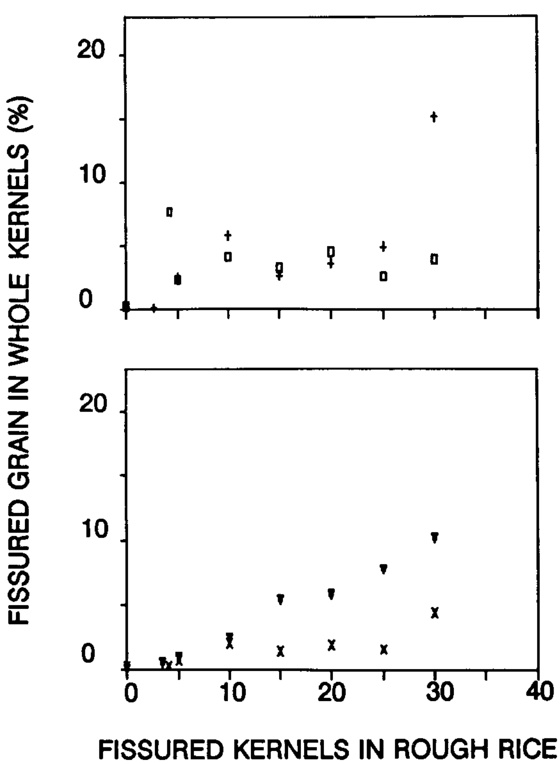

Fig. 5. Variation of fissured grain in whole kernels (based on rough rice) with fissured kernels in rough rice: Lemont (□), Labelle (+), Tebonnet (x), Newbonnet (∇).

TABLE V
Breakage of Fissured Kernels and Whole-Kernel Yield Reduction

A Fissures in Rough Rice (%)	B Fissured Grain in Whole Milled Rice (%)	C Fissured Kernel (A−B) (%)	D Whole Kernel Yield Reduction[a] (%)	E Whole Kernel Yield (%)
Lemont (C = 4.24)[b]				
0	0.31	···	···	58.57
10	4.13	5.87	9.13	49.44
20	4.54	15.46	14.29	44.28
30	3.94	26.05	19.88	38.69
Labelle (C = 2.73)				
0	0.09	···	···	67.40
10	5.78	4.22	2.97	64.43
20	3.65	16.35	14.39	53.03
30	15.20	14.80	22.19	45.21
Tebonnet (C = 4.04)				
0	0.03	···	···	68.22
10	2.00	8.00	9.21	59.01
20	1.63	18.37	18.87	49.35
30	4.45	25.55	22.32	45.90
Newbonnet (C = 3.44)				
0	0.02	···	···	68.46
10	2.45	7.55	8.12	60.34
20	5.87	14.13	13.73	54.73
30	10.20	19.80	18.83	49.63

[a] Indicates whole kernel yield at 0% fissures in rough rice less the whole kernel yield at 10, 20, and 30% fissures in rough rice, respectively.
[b] Control, i.e., the amount of fissured grains naturally present initially in the rough rice.

Linear regression models relating the percentage of fissured kernels in the rough rice to the whole-kernel yield and breakage in particular can be useful for commercial applications in fine tuning processing operations to produce a milled rice lot with the desired quality and head rice.

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