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Performance Analysis of an Impeller Husker considering the Physical and Mechanical Properties of Paddy Rice

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Some physical and mechanical properties of three varieties of rice namely; Akitakomachi (short grain), Delta and L201 (long grain) were determined and used in the performance analysis of an impeller husker. Grain motion on the blade was observed at the rated impeller speed of 2362 min^{-1} using a high-speed camera. The grain exit velocity resulted in an impact force above the yield force of the husk but below the yield force of the grain. However, the maximum friction force experienced on the blade was far below the yield shear force of the husk for all three varieties of rice. Husking tests were performed at different impeller speeds using a hard urethane liner, a soft polystyrene liner and without a liner. Type of liner significantly affected the husking performance. Short-grain rice had high husking energy capacity and cracked grain ratio, but a low broken grain ratio compared with long-grain rice. Performance curves for the three varieties of rice were well expressed by the Weibull's distribution function.

1. Introduction

Grain properties significantly affect their processing characteristics (Mohsenin, 1970; Sitkei, 1986), thus a clear understanding of their processing characteristics is important in minimizing losses and optimizing production to achieve higher efficiency. Since grain property variation is wide, especially when considering variety difference, rice cannot be considered to have uniform properties. Differences in grain properties can result in a significant variation in the processing characteristics of the grain. Nishiyama *et al.* (1992) simulated grain motion in the impeller husker and showed that husking occurs by friction and impact force. Yamashita (1993) in his case suggested that 20% to 50% of paddy is husked by the friction force on the impeller blade. However, there has been no link made between the husking performance of the husker and the properties of the grain. Due to the friction and impact force involved, emphasis is put on the removal of the husk with minimum energy and grain damage (Nishiyama, 1995). This requires optimization. Thus the objectives of this paper were:

(1) to determine some physical and mechanical properties of three different varieties of rice that relate to impeller husker performance;
(2) to evaluate the dynamic flow of paddy rice in an impeller husker and the effect of the impeller speed and liner type on the husking performance; and
(3) to develop empirical relations between performance and operation parameters based on Weibull's distribution function and thus optimize the husking performance.

2. Theoretical consideration

2.1. *Impact force analysis*

The basic equation for the impact of a body of mass m in kg, with initial velocity v_1 in $m\,s^{-1}$, before impact and final velocity v_2 in $m\,s^{-1}$, after impact, expressed as a change in momentum is given by

$$mv_1 - mv_2 = \frac{P_{max}\Delta t}{2} \qquad (1)$$

Notation

a, a_0, a_1, a_2, a_3	equation coefficient	t	time, s
B	broken grain ratio, %	Δt	duration of impact, s
b, b_3	equation coefficient	v_1	initial velocity, m s^{-1}
C	cracked grain ratio, %	v_2	final velocity, m s^{-1}
c, c_0, c_1, c_2, c_3	equation exponent	w	specific energy, kJ kg^{-1}
d	thickness of rough rice, m	X	operation parameter
E	Young's modulus, kN m^{-2}	X_0	minimum value of operational parameter
F_B	bio-yield force, N	Y	performance parameter
F_Y	yield force, N	Y_e	equilibrium performance value
F_s	shear force, N	Y_0	initial performance value
h	width of rough rice, m	z	deformation during compression of grain, mm
H	husked ratio, %	z_0	maximum deformation of grain, mm
k	gradient of force–deformation curve	α_r	radial acceleration, m s^{-2}
l	length of rough rice, m	α_T	transverse acceleration, m s^{-2}
m	mass, kg	β	equation coefficient
N	impeller speed, min^{-1}	γ	Poisson's ratio
N_{OPT}	optimal impeller speed, min^{-1}	η	energy efficiency, kg kJ^{-1}
N_0, N_1, N_2, N_3	minimum impeller speeds, mim^{-1}	θ	total angle of rotation of the grain, rad
P	normal force, N	μ	coefficient of friction
P_{max}	maximum impact force, N	ϕ	angular blade curvature, rad
R^2	correlation coefficient	ϕ_r	first derivative of ϕ with respect to r
r	radial displacement of grain, m	ϕ_{rr}	second derivative of ϕ with respect to r
r_g	radius of curvature of paddy rice, mm	ϕ_t	first derivative of ϕ with respect to t
r_0	initial radial position of grain, m	ϕ_{tt}	second derivative of ϕ with respect to t
r_1	maximum radial displacement, m	χ	constant
S	sphericity	Ψ	angle between the tangent to the blade and the radial direction, rad
		ω	angular velocity, rad s^{-1}

where $P_{\max}$ is the maximum impact force in kN, arising during impact at an arbitrary time Δt in *s*. The maximum impact force may be determined from the kinetic energy equation as shown below:

$$\frac{mv_1^2}{2} = \int_0^{z0} P\,\mathrm{d}z \tag{2}$$

where: P is the normal force in kN; z is the grain deformation in m; and z_0 is the maximum deformation in m, during impact. Based on Boussinesq theory (Sitkei, 1986), the grain deformation z during compression under a plane plate is expressed as

$$z = \left[0{\cdot}5625\left(\frac{1-\gamma^2}{Er_g^{0.5}}\right)^2\right]^{0{\cdot}33} P^{0{\cdot}67} = kP^{0{\cdot}67} \tag{3}$$

where γ, E and r_g are Poisson's ratio, Young's modulus in kN m^{-1}, and radius of curvature in m, respectively. The coefficient k is the gradient of the force–deformation curve of the grain. If the constant χ is given by

$$\chi = \frac{(1-\gamma^2)}{Er_g^{0{\cdot}5}} \tag{4}$$

then

$$\chi = 1{\cdot}33333k^{1{\cdot}5} \tag{5}$$

Substituting χ in the equation below gives the maximum deformation z_0 during impact for a spherical body:

$$z_0 = (0{\cdot}9375mv_1^2\chi)^{0{\cdot}4} \tag{6}$$

The duration of impact Δt is approximated from the following equation:

$$\Delta t = 2{\cdot}94\left(\frac{z_0}{v_1}\right) \tag{7}$$

The radius of curvature of grain is approximated from its length l in m, and thickness d in m, by the following equation (Yoshizaki & Miyahara, 1984):

$$r_g = \frac{l^2 + d^2}{4d} \tag{8}$$

2.2. *Simulation of grain motion on the impeller blade*

The profile of the impeller blade shown in *Fig. 1* can generally be described by the equation below (Nishiyama, 1991):

$$\phi = a + a \exp\,[b(r - r_0)]^c \tag{9}$$

where: a and b are equation coefficients; c is an exponent; and ϕ in rad defines the blade curvature with respect to its initial radial position r_0 in m, and radial displacement of grain r in m. If θ in rad is the total angle of rotation of the grain and ω in rad s^{-1} is the angular velocity of the blade, then radial a_r and transverse a_T acceleration in m s^{-2} (Cook & Pierce, 1960) of the grain are given by:

$$\alpha_r = \frac{d^2r}{dr^2} - r\phi_r^2\left(\frac{dr}{dt}\right)^2 - 2\omega r\phi_r\frac{dr}{dt} - \omega^2 r \tag{10}$$

$$\alpha_r = r\phi_r\frac{d^2r}{dt^2} + (r\phi_{rr} + 2\phi_r)\left(\frac{dr}{dt}\right)^2 + 2\omega\frac{dr}{dt} \tag{11}$$

where: ϕ_r is the first derivative of ϕ with respect to r; and ϕ_{rr} is the second derivative of ϕ with respect to r. If the angle between the tangent to the blade and the radial direction is Ψ in rad, then:

$$\tan\psi = r\frac{d\phi}{dr} = r\phi_r \tag{12}$$

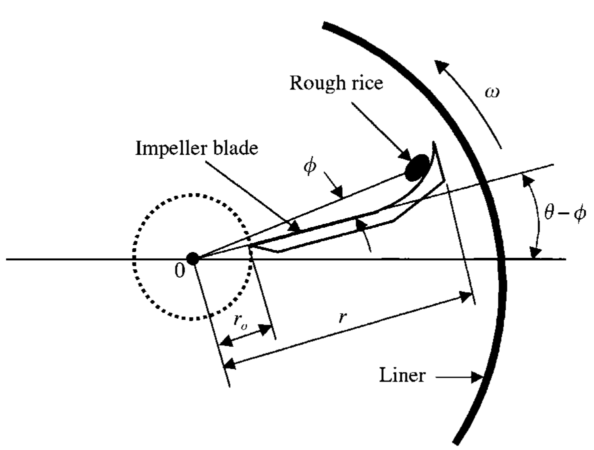

Fig. 1. Polar coordinate for grain position on the impeller blade: r, radial displacement of grain; r_0, initial radial position of grain; ϕ, angular blade curvature; θ, total angle of rotation of the grain; ω, angular velocity

Grain motion on the blade is thus expressed as follows (Nishiyama, 1991):

$$(r^2\phi_r^2 + 1)\frac{d^2r}{dt^2} + [r(r\phi_r + \mu)\phi_{rr} + \mu r^2\phi_r^3 + r\phi_r^2 + 2\mu\phi_r]\left(\frac{dr}{dt}\right)^2 + 2\mu\omega(r^2\phi_r^2 + 1)\frac{dr}{dt} + \mu\omega^2 r^2\phi_r - \omega^2 r = 0 \tag{13}$$

where, μ is the coefficient of friction between the grain and the blade. Differentiating Eqn (9) once with respect to time yields ϕ_t and second derivative yields ϕ_{tt} as shown below:

$$\phi_t = \phi_r\frac{dr}{dt}, \qquad \phi_\alpha = \phi_{rr}\left(\frac{dr}{dt}\right)^2 + \phi_r\frac{d^2r}{dt^2} \tag{14}$$

where ϕ_t is the first derivative of ϕ with respect to t and ϕ_{tt} is second derivative of ϕ with respect to time t in s. Substituting for ϕ_r and ϕ_{rr} in Eqn (13) with ϕ_t and ϕ_{tt}, respectively, yields a second-order differential equation in terms of radial displacement and time only. Normal force experienced by the grain on the blade is given by:

$$P = \frac{m}{\sqrt{r^2\phi_r^2 + 1}}\left[(r\phi_{rr} + r^2\phi_r^3 + 2\phi_r)\left(\frac{dr}{dt}\right)^2 + 2\omega(r^2\phi_r^2 + 1)\frac{dr}{dt} + \omega^2 r^2\phi_r\right] \tag{15}$$

2.3. *Performance and operation parameters*

Consider operation parameter X (for example, impeller speed) as the input and performance parameter Y (for example, husked ratio) as the output. Since the performance of the husker tends towards a maximum limit, based on Weibull's distribution function, the impeller performance parameters can be expressed as a function of the operation parameters as shown below:

$$F(X) = \frac{Y - Y_e}{Y_0 - Y_e} \tag{16}$$

where Y_0 and Y_e are the initial and equilibrium performance values, respectively. The function $F(X)$ can therefore be expressed as follows in terms of the minimal operation value X_0 and a given operational value X (Nishiyama *et al.*, 1979; Shitanda *et al.*, 1998).

$$F(X) = \exp\{-[a_0(X - X_0)]^{c_0}\} \tag{17}$$

where, a_0 is an equation coefficient and c_0 is an exponent. For performance parameters expressed as a percentage, the value for Y_0 is 0% and that for Y_e is 100%. When the operation parameter for the husker is the impeller speed N in min^{-1}, and the performance parameter $Y\%$ is the husked ratio, broken grain ratio or cracked grain ratio, then Eqn (16) can be expressed as follows:

$$Y = 100 - 100 \exp\{-[a_0(N - N_0]^{c_0}\} \tag{18}$$

where, N_0 is minimum impeller speed in min^{-1}.

2.4. *Optimization of husking performance*

Specific husking energy w in kJ kg^{-1} for impeller husker is given by the following equation (Sugawara, 1995):

$$W = \beta N^2 \tag{19}$$

where, β is an equation coefficient. Considering the husked ratio $H\%$ as output and specific husking energy as input, the authors have proposed a new husking performance optimization parameter C_h in kg kJ^{-1} (Shitanda *et al.*, 1999) expressed as follows:

$$C_h = \frac{H}{100\,w} \tag{20}$$

The parameter C_h is referred to as husking energy capacity since it is a measure of the husked grain per unit of the supplied energy. When husking energy capacity is maximum, husking performance is said to be optimal. This occurs when the following equation satisfied:

$$\left(\frac{\mathrm{d}C_h}{\mathrm{d}w}\right) = 0 \tag{21}$$

At maximum husking energy capacity, impeller speed N_{OPT} in min^{-1} is referred to as optimal impeller speed.

3. Materials and methods

Three different varieties of rice used were Akitakomachi (short grain), Delta and L201 (long grain). Bio-yield point, and yield point were determined using a stress–strain tester by compressing rough rice on a metallic flat surface at $0{\cdot}14\ \text{mm s}^{-1}$. A computer simultaneously recorded the compression force and time from the tester. Grain deformation was then calculated and the force–deformation curves plotted. Compression was stopped when cracking of the grain was heard. The husk was then manually removed to confirm the yield. From the force–deformation curves, k was determined and then used to calculate χ which was then substituted in Eqn (6) to obtain the maximum deformation. Maximum impact force was estimated using Eqn (2), the duration of impact using Eqn (7) and final velocity of the grain after impact using Eqn (1). Yield shear force was determined as the maximum husking force between two rubber rolls using the arrangement shown in *Fig. 2*. A computer simultaneously recorded shear force and time.

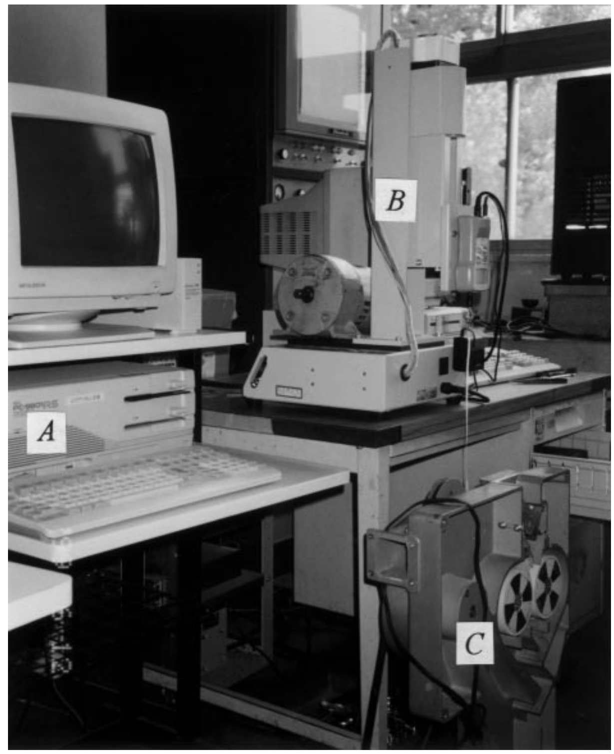

Fig. 2. Experimental arrangement for determination of shear force of rice husk using rubber rolls: A, computer; B, stress–strain tester; C, rubber roll husker

Husking of the rice was carried out using the impeller husker shown in *Fig. 3* with a hard urethane liner, a soft polystyrene liner and without a liner. The husker had eight blades of surface length 0·13 m, radial length of 0·118 m, and a rated impeller speed of $2362\ \text{min}^{-1}$. The initial radial position r_0 is 0·037 m and the maximum radial displacement r_1 is 0·155 m. Clearance between the liner and the blades is about 0·015 m. The soft liner was covered with a soft plastic tape for easy identification of impact marks. Impeller speed was varied between 1400 and $3300\ \text{min}^{-1}$ by an electrical inverter and calibrated using a digital contact tachometer. The grain properties determined were moisture content, radius of curvature, length, width, thickness, and weight. About 50 g of uniformly selected rough rice at 15% w.b moisture content was husked at the rate of $0{\cdot}027\ \text{kg s}^{-1}$ and the weight of the husked, unhusked, broken and cracked grain determined. Cracks in the rice were detected using a grain scope and a digital power meter was used to measure husking power. A high-speed camera was used to observe time and radial displacement of the grain (Delta) on the blade. Grain motion was simulated by Eqn (13) using

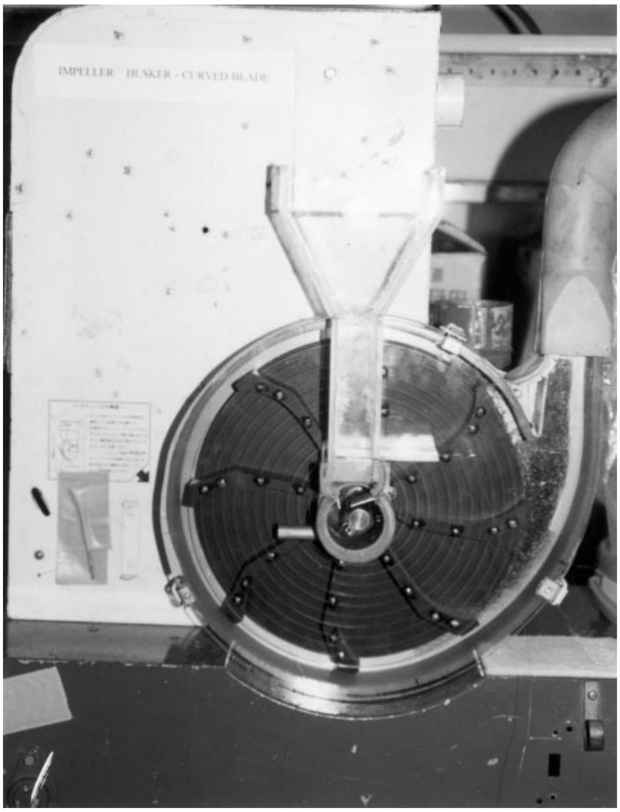

Fig. 3. Experimental impeller husker showing impeller blades and urethane liner

a coefficient of friction of 0·5. The equation was solved using Runge Kutta method (Thomas & Finney, 1988).

4. Results and discussion

4.1. *Grain properties and dynamics*

The grain properties, which were measured and calculated, are given in Table 1. The variety Akitakomachi had the lowest radius of curvature followed by Delta and L201. However, the reverse was true for the sphericity S. *Figure 4* shows the force–deformation curves of the three varieties of rice. Yield shear force F_S of the husk was found to be close to half the bio-yield force F_B of the grain. Considering the maximum shear stress criterion (Crandall *et al.*, 1978), the results obtained show that the bio-yield point is a good approximation of the yield point for the husk. It can thus be used to estimate the yield shear force of the husk. The bio-yield point for the three varieties of rice were very close together showing that this point is not very dependent upon the rice variety. Long-grain rice, however, showed a slightly higher yield force F_Y compared with short-grain rice. The manually husked compressed grains were found to have heavy cracks explaining the deflection at the yield point.

The coefficients and exponent for Eqn (9) for the three varieties of rice are given in Table 2. Variation of radial displacement of the grain r in m, with time t in s, of the grain on the blade is given by:

$$r = 0{\cdot}118 - 0{\cdot}118 \exp(-\lfloor 28895\, t^2 + 0{\cdot}392 \rfloor) + 234{\cdot}822 t^2 \qquad (22)$$

From Eqns (8) and (22), the resultant experimental grain exit velocity determined was about 44·8 m s^{-1} and the maximum specific normal force experienced on the blade was about 15·4 kN kg^{-1}. The corresponding simulated values were 42·9 m s^{-1} and 11·3 kN kg^{-1}, respectively. There was a good agreement between the experimental and the simulated values as shown in *Fig. 5*. However, in both cases the maximum friction force of 0·3 N experienced on the blade was far below the yield shear force of the three varieties of rice. Thus, husking was unlikely to occur on the blade by friction force.

Theoretical impact force F_I of the three varieties of rice computed by Eqn (1) and yield force F_Y are given in Table 1. Delta had the highest impact force of 45·4 N

Table 1
Properties of different varieties of rough rice

Property	*Rice variety*		
	Akitakomachi	*Delta*	*L201*
Length l, mm	7·3	10·0	9·8
Width h, mm	3·3	3·2	2·5
Thickness d, mm	2·3	2·2	2·0
Mass m, kg	0·0286	0·0374	0·0275
Sphericity S	0·52	0·41	0·37
Radius of curvature r_g, mm	6·36	11·91	12·51
Shear force F_S, N	5·1	9·7	8·6
Bio-yield force F_B, N	17·2	18·9	18·8
Impact force F_I, N	35·2	45·4	37·1
Yield force F_Y, N	56·2	63·4	62·9

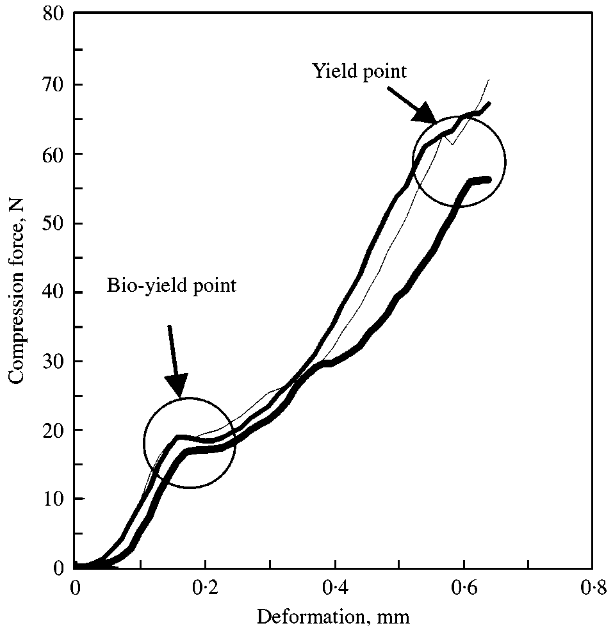

Fig. 4. Variation of compression force with deformation for different varieties of rice: ▬, *Akitakomachi;* ▬, *Delta;* ——, *L201*

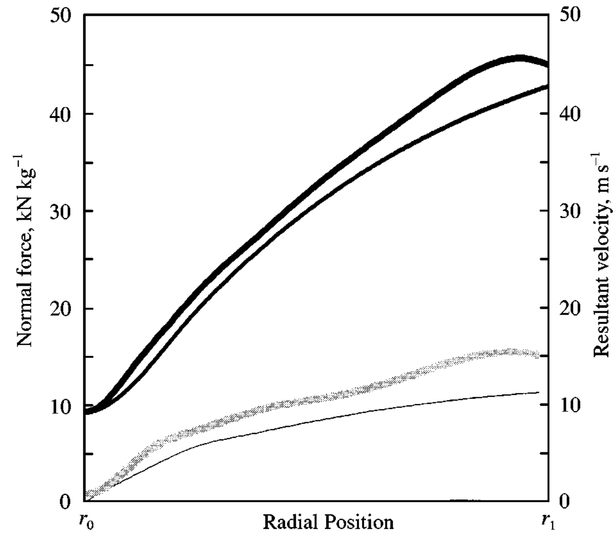

Fig. 5. Experimental and simulated normal force and resultant grain velocity on the impeller blade: ▬, *experimental velocity;* ▬, *simulated velocity;* ~~~, *experimental force;* ——, *simulated force; r_0, initial radial position; r_1, maximum radial displacement*

and yield force of 63·4 N followed by L201 and Akitakomachi. The impact force was below the yield force but above the bio-yield point for the three varieties of rice. It was therefore high enough to break the husk with minimal grain damage. Final grain velocity v_2 was relatively independent of the grain variety and was about 24 m s^{-1}. Results showed that the grain bounced back fast enough to be hit by the oncoming blade. Due to the high final velocity, blade impact is likely to occur more than once explaining the wide range of the impact zone seen on the plastic tape attached on the soft liner.

From the blade curvature, the grain incident angle on the liner is about 41°. Assuming the incident angle is equal to the exit angle, then the resultant tangential impact velocity of the grain on the blade is about 54 m s^{-1}. Therefore, the maximum impact force by the blade is about 44·3 N for Akitakomachi, 56·8 for Delta and 46·4 for L201. Although the impact force by the blade is below the yield point of the three rice varieties, it is above their bio-yield point and higher than the impact force on the liner. Thus, a good portion of the grain is likely to have been husked by the blade impact. At the rated impeller speed, the observed grain exit zone ranged between 0 ~ 90° from the normal when the blade had turned through 135 ~ 230°.

4.2. *Husked ratio*

Husked ratio increased with the impeller speed as shown in *Fig. 6*. Husked ratio curves for the three varieties of rice were well expressed by Eqn (18) as shown below:

$$H = 100 - 100 \exp\{ -[a_1(N - N_1)]^{c_1}\} \qquad (23)$$

Equation coefficient a_1 given in Table 2 did not vary much with the rice varieties but the minimum impeller

Table 2

Equation parameters for evaluating the blade curvature, husked ratio, cracked grain ratio and broken grain ratio; a, a_1, a_2, a_3, coefficients; b, b_3, coefficients, c, c_1, c_2, c_3, exponents; N_1, N_2, N_3, minimum impeller speeds, min^{-1}

Grain variety	*Blade curvature*			*Husked ratio*			*Cracked grain ratio*			*Broken grain ratio*			
	a	b	c	a_1	N_1	c_1	a_2	N_2	c_2	a_3	b_3	N_3	c_3
Akitakomachi	0·00254	35·594	1	0·0019	1087·5	1·66	0·000068	783·4	2·49	7·265	0·00016	1097·6	1·66
Delta	0·00254	35·594	1	0·0014	1068·7	1·88	0·00018	654·8	2·82	—	—	—	—
L201	0·00254	35·594	1	0·0014	1086·2	1·83	0·0031	645·8	2·75	0·245	0·0023	1088·1	3·81

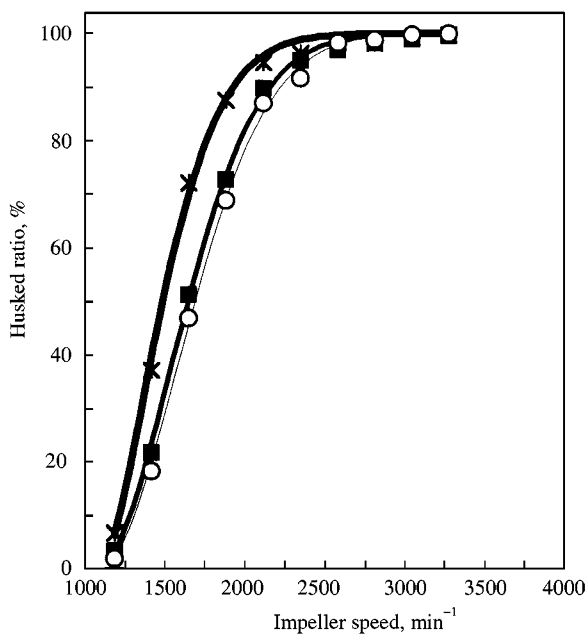

Fig. 6. Variation of husked ratio with impeller speed for different varieties of rice husked using urethane liner: —✳—, *Akitakomachi;* —■—, *Delta;* —○—, *L201*

speed $N_1 \equiv N_0$ with respect to husked ratio showed some dependency on the weight of the grain. Equation (23) had high correlation coefficient R^2 of 0·997, 0·997 and 0·990 for Akitakomachi, Delta and L201, respectively. The exponent c_1 for the three varieties of rice was well approximated as follows:

$$c_1 = \frac{\sqrt[3]{lhd}}{h} \tag{24}$$

where, h is the grain width in m. The above equation is similar to the sphericity equation showing that the equation exponent is dependent on the shape of the grain.

The husked ratio curves for the hard urethane and soft polystyrene liner were similar, but the latter resulted in a low husked ratio. At the rated impeller speed, the three varieties of rice had a husked ratio of over 90% using urethane liner. It however reduced by 55% for Akitakomachi, 35% for Delta and 55% for L201 when the soft liner was used. Without the liner, less than 20% of the grain was husked showing that over 80% of the husking occurred by impact force on the liner and on the blade. Thus the percentage of grain husked on the blade by friction force is lower than the 20 ~ 50% earlier presumed.

4.3. *Husking energy capacity*

Specific husking energy increased with the impeller speed but did not vary significantly with the grain variety. Based on Eqn (19), the specific husking energy was given by

$$w = 1{\cdot}149 \times 10^{-6}\, N^2 \tag{25}$$

The husking energy capacity of the three varieties of rice shown in *Fig. 7* was higher for short-grain rice compared to long grain rice. Optimal impeller speeds were 1655 min^{-1}, 1836 min^{-1} and 1882 min^{-1} for Akitakomachi, Delta and L201, respectively. Their corresponding husked ratios were 70·7%, 69·6% and 69·4%, respectively. Since the above husked ratios are below the 90% recommended for the impeller husker (Yamashita, 1993), the results showed that impeller speed could not solely be used to optimize the husker performance. This is because any further increase in impeller speed not only increases husked ratio but also grain damage as shown in Sections 4.4 and 4.5.

4.4. *Broken grain ratio*

Broken grain ratio B% increased with the impeller speed as shown in *Fig. 8*. At the optimal impeller speed, the broken grain ratios were, 0·1%, 1·1% and 6·8% for Akitakomachi, Delta and L201, respectively. This showed that short-grain rice was tougher compared with long-grain rice since it was hard to break Similar to the husked ratio, broken grain ratio was also well expressed by Eqn (18) as follows:

$$B = 100 - 100 \exp\{-[a_2(N - N_2)]^{c_2}\} \tag{26}$$

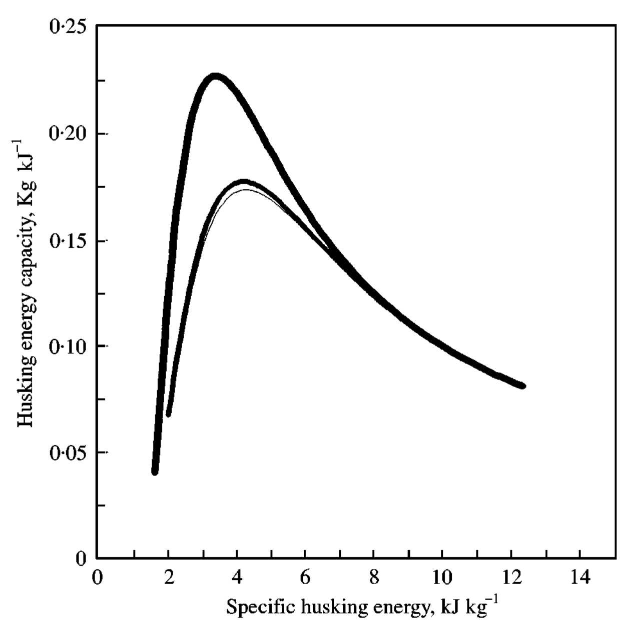

Fig. 7. Husking energy capacity of different varieties of rice husked using urethane liner: ▬▬, *Akitakomachi;* ——, *Delta;* ——, *L201*

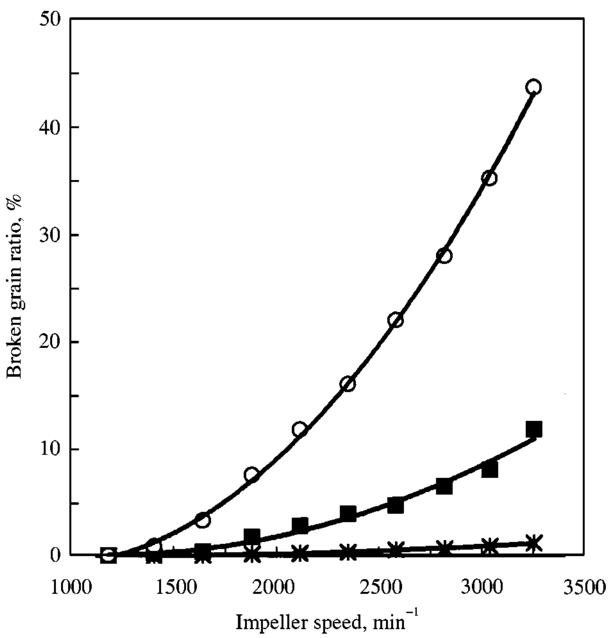

Fig. 8. Effect of impeller speed on broken ratio for different varieties of rice husked using urethane liner: —✱—, *Akitakomachi;* —■—, *Delta;* —○—, *L201*

Equation coefficient a_2 given in Table 2 varied with the grain variety whereas the minimum impeller speed $N_2 \equiv N_0$ with respect to broken grain ratio was slightly lower but close to that for long-grain rice. Equation (26) had a high correlation coefficient R^2 of 0·992, 0·983 and 0·998 for Akitakomachi, Delta and L201, respectively. The exponent c_2 was well estimated as follows:

$$c_2 = 1{\cdot}5c_1 \quad (27)$$

Use of the soft liner reduced the broken grain ratio by over 50%, and a further reduction occurred when the liner was removed. Results show that grain breakage occurred mainly by impact force in the impeller husker.

4.5. *Cracked grain ratio*

Cracked grain ratio C% for Akitakomachi and L201 increased with the impeller speed as shown in *Fig. 9*, and was well expressed by Eqn (28) which had a high R^2 value of 0·991 and 0·992 for Akitakomachi and L201, respectively. However, cracked grain ratio for Delta increased to a maximum and then decreased as the impeller speed increased.

$$C = a_3 - a_3 \exp\{-[b_3(N - N_3)]^{c_3}\} \quad (28)$$

Equation coefficients a_3 and b_3, and exponent c_3 are given in Table 2. At the optimal impeller speed, Akitakomachi had the highest cracked grain ratio of about 3·8% followed by Delta, 1·8% and L201, 0·24%. Considering the broken grain ratio results, it is seen that short-grain rice was easy to crack but hard to break whereas the converse was true for long-grain rice, which exhibited brittle characteristics. This explains the low and decrease in the cracked grain ratio as the impeller speed increases for long-grain rice. Cracked grain ratio, like husked ratio and broken grain ratio, was reduced by over 50% when the soft liner was used and by over 95% when the liner was removed as shown in *Fig. 10*. Thus cracked grain ratio results for hard, soft and no liner also showed that cracks occurred mainly due to impact force in the impeller husker.

5. Conclusions

(1) The yield shear force of the husk is about half the bio-yield force of rough rice.
(2) Over 80% of rough is husked by the impact force on the liner and by the blade. Impact force is the main cause of grain damage.
(3) The tough nature of short-grain rice results in a low broken grain ratio but a high cracked grain ratio, which is the reverse of results for the brittle long-grain rice.
(4) Performance curves for the impeller husker are well expressed by empirical equations based on Weibull's distribution function irrespective of the rice variety.

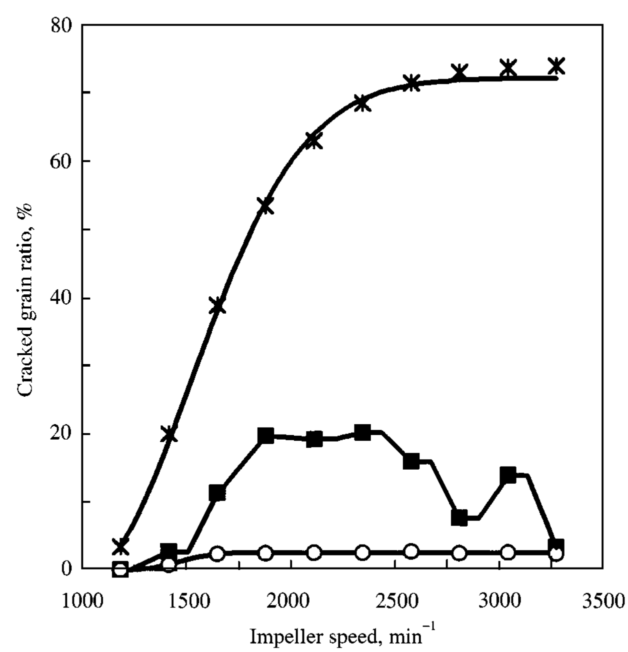

Fig. 9. Variation of cracked ratio with impeller speed for different varieties of rice husked using urethane liner: —✱—, *Akitakomachi;* —■—, *Delta;* —○—, *L201*

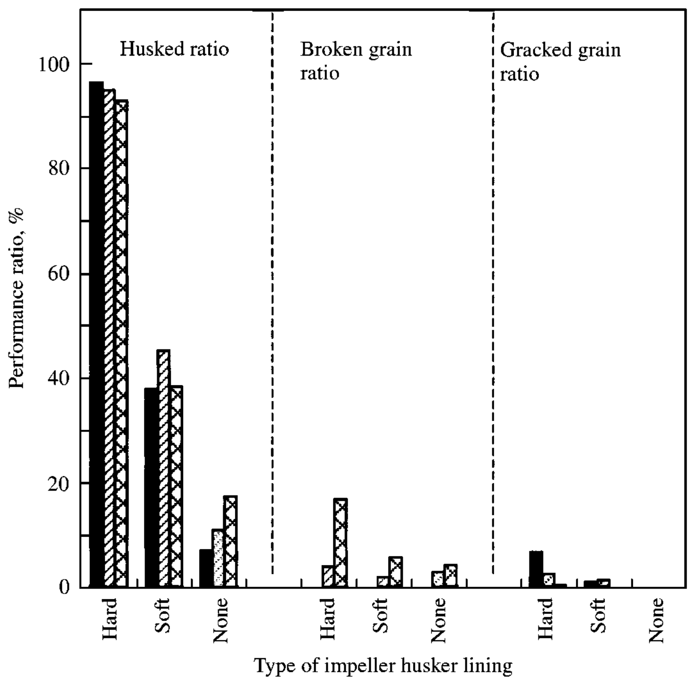

Fig. 10. Effect of hard, soft and no liner on the performance of impeller husker as given by the husked ratio, broken grain ratio and cracked grain ratio for three varieties of rice: impeller speed, 2362 min^{-1}; ■, Akitakomachi; ▨, Delta; ⊠, L201

(5) Husking characteristics of rough rice are dependent upon its shape and size.
(6) Impeller speed cannot be solely used to optimize the performance of impeller husker due to low husked ratio at optimal impeller speed.

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